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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

EXPLORING THE REDUCTION OF FUEL CONSUMPTION FOR SHIP-TO-SHORE CONNECTORS OF THE MARINE EXPEDITIONARY BRIGADE

by

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Cohort 311-122O

December 2013

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At the beginning of the 21st century, the United States Marine Corps (USMC) took a leading role in the war on terror. The traditionally amphibious force deployed massive amounts of troops and supplies in two major land wars of occupation. Now, as the USMC winds down its participation in the conflicts, it must seek to return to its roots as a primarily amphibious force without the benefits of a land-based operation. Tomorrow's battles will likely begin from the littorals in and around the coastal regions of the developing world. The Marine Corps must prepare itself to operate without the benefit of readily available fossil fuels and supplies shipped in by trucks or home-based supply lines. As demonstrated in the current conflicts, the threats of IEDs and the expenses of obtaining fossils fuels make it imperative that the Marine Expeditionary Brigade (MEB) of the future must be able to bring its supplies with them or have them delivered by readily available and close-by alternate means. This research will evaluate the current landing doctrine of a notional MEB and its associated ship-to-shore connectors. It will analyze potential changes in doctrine with the goal of reducing energy footprint while maintaining mission effectiveness.

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EXPLORING THE REDUCTION OF FUEL CONSUMPTION FOR SHIP-TO-SHORE CONNECTORS OF THE MARINE EXPEDITIONARY BRIGADE

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ABSTRACT

At the beginning of the 21^{st} century, the United States Marine Corps (USMC) took a leading role in the war on terror. The traditionally amphibious force deployed massive amounts of troops and supplies in two major land wars of occupation. Now, as the USMC winds down its participation in the conflicts, it must seek to return to its roots as a primarily amphibious force without the benefits of a land-based operation. Tomorrow's battles will likely begin from the littorals in and around the coastal regions of the developing world. The Marine Corps must prepare itself to operate without the benefit of readily available fossil fuels and supplies shipped in by trucks or home-based supply lines. As demonstrated in the current conflicts, the threats of IEDs and the expenses of obtaining fossils fuels make it imperative that the Marine Expeditionary Brigade (MEB) of the future must be able to bring its supplies with them or have them delivered by readily available and close-by alternate means. This research will evaluate the current landing doctrine of a notional MEB and its associated ship-to-shore connectors. It will analyze potential changes in doctrine with the goal of reducing energy footprint while maintaining mission effectiveness.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	Anti-Access/Area Denial
ACE	Aviation Combat Element
AOR	Areas of Operation
ARG	Amphibious Ready Group
BOE	Back of the Envelope (model)
E2O	Expeditionary Energy Office
EW12	Expeditionary Warrior 2012
DOE	Design of Experiments
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Unit
MAGTF	Marine Air-Ground Task Force
MEB	Marine Expeditionary Brigade
MOE	Measure of Effectiveness
MOP	Measure of Performance
NOLH	Nearly Orthogonal Latin Hypercube
OFAT	One Factor at a Time
SSD	Seabase Standoff Distance
TRL	Technology Readiness Level
USMC	United States Marine Corps
VERTREP	Vertical Replenishment

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EXECUTIVE SUMMARY

In the new battle-space of the 21st century, the United States Marine Corps (USMC) will have to be able to operate with fewer supplies and fossil fuels. With this in mind, in 2010 the Commandant of the USMC addressed the direction of the Corps with respect to self-sufficiency on the battlefield:

> A middleweight force, we are light enough to get there quickly, but heavy enough to carry the day upon arrival, and capable of operating independent of local infrastructure. (Amos 2010, 5)

The USMC has also acknowledged that during major occupied combat operations in recent theatres, its dependence on liquid fuel and fresh water was a major vulnerability. This dependence requires supply lines to be protected which removes forces that otherwise would be able to be engaged in offensive combat operations. Additionally, it allows the enemy an easily attained victory in the severing of supply lines.

> The future security environment requires a mindset geared toward increased energy efficiency and reduced consumption, thus allowing us to operate lighter and faster. (Amos 2010, 5)

With the goal of increased efficiency, the USMC Expeditionary Energy Office (E2O) was formed in 2009. The E2O website (Expeditionary Energy Office, 2013, About Us) states a mission to:

> Analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all warfighting functions.

The E2O tasked this project team with the challenge of improving energy efficiency of a Marine Expeditionary Brigade during an amphibious landing prior to an Anti-Access / Area Denial (A2AD) mission. The research focuses on answering the following research question:

- Can improved fuel efficiency be reached through changes in Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) while maintaining mission capability?

The report examines solutions to this and other follow on questions by varying the amount and types of connectors (ships or aircraft that deliver personnel and equipment

from large amphibious ships to shore) used during an amphibious operation in addition to exploring DOTMLPF considerations and capability/force size to accomplish the mission.

The capstone project team used a Systems Engineering (SE) approach to explore variations of the connector network for a Marine Expeditionary Brigade (MEB). Additionally, the team employed modeling and simulation tools to validate the proposed changes to the current architecture of the MEB during A2/AD operations. Given the stakeholder's inputs, the traditional SE process was used to decompose the stakeholder objectives into functions that could be allocated into physical components for analysis. In order to analyze the effects of changes designed to reduce energy footprint of MEB operations, it was desirable to have a realistic MEB scenario. Rather than creating a notional MEB architecture, the team chose Expeditionary Warrior 2012 (EW12), which is a Marine Corps Title 10 Wargame. The EW12 scenario explores the A2/AD mission, in a fictional nation in Western Africa in the year 2024.

The backdrop of EW12 provides the traceability from the notional architecture to the realistic organization of troops to accomplish a mission. This traceability allowed the team to determine Measure of Effectiveness (MOE) that would be applicable to use for evaluating both the current structure of the MEB, its connectors, and any proposals that would make tradeoffs to reduce the energy footprint of the MEB. These MOE's are listed below with their applicable Measures of Performance (MOP).

- MOE #1: Throughput of the connector system – Capability of Connectors to transport MEB
  - MOP #1: Utilization of Service bays at seabase include consideration of:
    - Number of well deck bays available for surface connectors
    - Number of connectors actively serviced
    - The percent of bays that are utilized over time.
  - MOP #2: Average delay of connectors waiting to transport MEB
- MOE #2: Reduction of fuel consumed by MEB during the conduct of an amphibious assault over a baseline configuration
  - MOP #1: Fuel consumed by connectors during conduct of amphibious assault

The EW12 scenario was closely examined to determine the set of functions that would compose the proposed architecture as well as the functional requirements of an A2/AD mission. EW12 planners broke its operation into three distinct phases:

- Phase I: Achieve Access
    - Establish base at Savannah Islands and establish support for seabase operation
- Phase II: Gain Entry
    - Seizure of a lodgment and the rapid introduction of forces
    - Mount an attack to secure the (fictional) city of Touba
    - Continue to expand the aerial and sea ports of debarkation
- Phase III: Follow-on Operations
    - Support follow-on operations. (Wargaming Division. 2012, 8)

Initially, Phases I and III were determined to be outside the scope of the team's primary research. Through the research necessary to perform the analysis on Phase II, Phase III was later determined to be applicable as potential follow on research. Phase II: Gain Entry, and specifically on the vignette "Seizure of a lodgment and the rapid introduction of forces" (Wargaming Division. 2012, 8) was chosen for its potential for efficiency improvements. EW12 Functional Architecture was further decomposed to include functions specific to the seize lodgment objective and the transport of cargo, troops, and vehicles to the beachhead from an established seabase. Each type of connector was examined functionally in order to represent its role in the overall operation. Using these findings, the functional architecture for each connector was modeled in CORE, a systems architecting software tool, to ensure consistency and completeness. This level of the functional architecture could then be assessed using a model-based system engineering approach, to include computer simulation of the ship-to-shore movements of the MEB.

The team chose to use discrete event modeling in order to research tradeoffs to reduce fuel consumption, while still maintaining mission effectiveness. ExtendSim discrete event modeling software was utilized in order to build a stochastic model of the notional MEB architecture framework. In order to perform quality checks and discover

design errors, the model was checked against an analytical model created using MS Excel.

The stochastic model was developed to represent the unique functions of the two main connector types; the surface connectors (Landing Craft Unit [LCU] and Landing Craft Air Cushion [LCAC]) and the air connectors (MV-22, CH-53 and UH-1Y). In addition to the physical connectors, the model also included the queuing capacities and processes of the seabase loading sites, and the Beach Support Area (BSA) landing zones. These aspects were intended to examine whether seabase or BSA servicing capacities had an effect on overall system performance. Factors such as sea state and Seabase Standoff Distance (SSD) were selected to influence operational effects and limitations on the system's performance. Once proper stochastic model performance was verified, a Design Of Experiments (DOE) approach was employed in order to determine the major influences that the variables exerted on the system architecture design.

During the simulation sequencing, the tempo of the events is set by two distinct phases; the "Assault" phase and the "Sustainment" phase. The assault phase is further decomposed into five (5) discrete waves, with the assault force converted into equivalent weight for the purposes of the simulation. An efficiency factor of 90% was applied to each connector to account for imperfections in the real-life process. Following the completion of the Assault phase, the simulation progresses to a "Sustainment" phase, which spans the remainder of the of the 30 Day amphibious assault mission.

Once the DOE variables and the Noise Variables were defined, the relationships between these variables and the output responses were explored to determine the effects of the input variables on the output responses.

In order to establish factors of interest for evaluation, a preliminary 2-Level Factorial simulation experiment was developed. The Full Factorial experimental design was performed through the ExtendSim discrete event model. Given the initial results, the team was able to infer the following about the data:

- The Seabase Distance and Sea State parameters have the most direct impact on both timely completion of the assault phase, as well as fuel economy

- The interaction of the Seabase Distance and Sea State factors is also a significant response. The fact that there is a positive coefficient implies that increases to Seabase Distance and Sea State significantly increase both the time to complete the operation and the fuel used during the operation.

A Linear Regression model was generated given the input variables in order to observe the weighted contributions of the variables to the output responses. The results show the proportional weights that each input variable has on the output response. The Seabase Distance and Sea State factors possess the largest impact on both Assault Time and Fuel Usage metrics.

As a follow up excursion to the wide range of variables initially explored, it was decided to test a connector configuration representative of a typical Amphibious Ready Group (ARG). The ARG is the group of ships both offensive, transport/supply, and amphibious tasked with delivering and supporting the MEB ashore. This configuration represents a capability baseline in which to evaluate performance of the system. For this second iteration of simulation, a Nearly Orthogonal Latin Hypercube (NOLH) design was selected for this experiment. The NOLH design allows a wide range of factor space to be explored, with a minimal impact of correlation error. This experimental design was executed through the ExtendSim discrete event simulation model.

Following completion of the DOE trial, it was determined that sufficient information was available to develop inferences on system performance and provide recommendations to the project stakeholder.

With the intent of answering the research questions derived from the sponsor, the following responses are provided with respect to the research questions.

Research Question 1: "Can Improved Fuel Efficiency be Reached through Changes in DOTMLPF while Maintaining Mission Capability?"

There are several different ways in which fuel efficiency can be obtained through Doctrine changes in this mission area. However, the extent of fuel savings achieved may vary on factors within the MAGTF's control as well as some variables outside of direct control. It was documented that fuel savings are directly proportional to the Seabase distance and sea state effects during operations, which may not always be able to be

influenced by the landing force. However, it was determined that when these adverse conditions exist, the LCU may be able to provide better fuel economy over employment of the LCAC.

As consistent with current doctrine and best practices, the model validates the planning considerations with respect to SSD and sea state. The model provides statistical evidence to support the recommendation that these two factors should be minimized when practical to gain best efficiencies when conducting the assault.

Significant interactions exist when operating LCACs and LCUs in different SSD conditions. The quantity of LCACs and LCUs are not significant when operating at a close distance from shore; however, as the standoff distance is increased, the quantity of landing craft connectors becomes more significant.

Research Question 2: "What Particular Connectors Have the Most Effect on Fuel Efficiency?"

The LCAC and MV-22 connectors have the most significant negative effects on overall fuel efficiency during the mission. However, it was determined that the LCAC also has the most positive effect on performance of the Amphibious Assault mission, thus its employment should be considered judiciously when favoring payload throughput vs. fuel efficiencies. It was determined that the use of MV-22 should be further reviewed for its operationally effective contributions to system performance.

Research Question 3: "Can the Environment Affect the Ability of the MEB to Achieve Better Fuel Efficiency?"

This question was satisfactorily answered by this study. Environmental effects such as Sea State have a pronounced negative effect on fuel efficiency. However, this effect can be mitigated to an extent through operational workarounds, such as decreasing the SSD, and employing LCUs in place of LCACs. When operating in high sea states cannot be avoided, accommodations in SSD is not possible, there are still efficiencies possible to be gained in this scenario. The negative effects of the Assault Time by high Sea State can be mitigated by increasing the quantity of LCUs or LCAC connectors. When considering the interests of fuel efficiencies, increasing the quantities of LCUs during high sea state provides less of an impact on fuel consumption than that of the LCACs. Thus, the recommendation is provided as follows:

- When conducting the amphibious assault in high sea state conditions, it is recommended to decrease the SSD as operationally practicable.
- When the above recommendation is not feasible, it is recommended to utilize LCUs to conduct the landing craft operations over LCACs to optimize energy efficiencies in this operational scenario.

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I. INTRODUCTION

A. PURPOSE

The purpose of this research is to analyze potential changes in amphibious operations and area denial/anti-access (A2/AD) mission with the goal of reducing energy footprint while maintaining mission effectiveness. This problem is posed by the United States Marine Corps (USMC) Expeditionary Energy Office (E2O) to Naval Postgraduate School (NPS) Cohort SE311-122O. This analysis examined the doctrine, training, organization, and deployment of a notional Marine Expeditionary Brigade (MEB) while conducting an A2/AD mission. Additionally, it used systems engineering processes to explore the best ways to reduce energy consumption of the MEB. The results of the analysis were used to identify areas that the USMC and the E2O may wish to focus future research on in order to reduce the energy consumption of the MEB.

B. BENEFITS OF STUDY

The research seeks to offer suggestions for changes to doctrine, training, organization, and leadership that the E2O office can choose to implement or explore further. The end goal of these recommendations is the achievement of predicted increases in energy efficiency of the MEB while maintaining mission effectiveness in the A2/AD environment. It is the goal of the Cohort that the A2/AD mission analysis will help the E2O make selections regarding future studies of the MEB operations at increasing levels of detail.

C. USMC 21ST CENTURY WARFIGHTING CONSTRAINTS

As the USMC has been tasked with occupational roles, as seen in Iraq and Afghanistan, it has been forced to become more dependent on large supply depots and massive amounts of liquid fuel and supplies. These requirements stem from two primary sources, which are the non-traditional threats facing the Corps and the power and fuel required to perform the mission and needed to support the MEB. The previously

lightweight and fast moving force now has a large footprint of troops and materiel needed to function as an occupational army.

The increased size of the USMC stems from the need for a local presence both on and off the battle field. Personnel may be required to patrol an area one day, fight an enemy the next, and build a school the following day. This constant change of roles requires power and energy to sustain both war fighting efforts and balance it with the "winning of hearts and minds."

The way in which the enemy fights has also changed. Lacking traditional war fighting methods and facing a technologically superior foe has led to the widespread proliferation of Improvised Explosive Devices (IEDs) on the battlefield. As the casualties from IEDs in the theaters of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) increased, the amount of armor per vehicle and the number of vehicles required has grown, reducing the fuel efficiency and increasing the dimensions and weights of the vehicles that are deployed. While newer and more resistant vehicles have been deployed, they sacrifice efficiency for protection, making them large users of resources in exchange for the safety of troops.

Given the force size and the march of technology, power requirements for the MEB have also gone up. Every aspect of the battlefield now has some form of electronic equipment either connected to or charged by batteries and portable generators. This increase in the demand for electrical power has compounded the need for fossil fuel consumption on and off the battlefield, which also increases the need for fuel delivery and security forces to protect the delivery vehicles. The size of the battle field is also no longer limited to the traditional model. With the added technological advances in communications and surveillance, the force can be moved across a much greater distance, such as an entire country, so it is imperative to find even more ways to use fuels efficiently in order to drive down the need of resupply.

The convergence of these factors has resulted in a MEB fighting force that is dependent upon extensive amounts of fossil fuels. Whether provided by truck, plane, or

ship, the MEB cannot function to current standards without it. A successful attack on or limitation of these supply lines will leave the MEB vulnerable and reduce its mission effectiveness.

D. COMMANDANT OF THE MARINE CORPS COMMANDANT'S PLANNING GUIDANCE 2010

The USMC has always been an expeditionary force, in a constant state of readiness, operating from the sea. In the new conflicts that are anticipated to occur in the 21st century, the USMC will have to be able to operate with fewer supplies and fossil fuel. This is due to the necessity of the USMC to operate in areas that are not sufficiently developed to be able to transport supplies with ease. The threat environment also makes the MEB vulnerable to attack on its supply convoys. In 2010, the Commandant of the USMC addressed the direction of the USMC with respect to self-sufficiency on the battlefield: "A middleweight force, we are light enough to get there quickly, but heavy enough to carry the day upon arrival, and capable of operating independent of local infrastructure" (Amos 2010, 5).

The USMC has been directed to reduce its dependence on supplies and fossil fuels in order to improve its agility and autonomy on the battlefield. This will result in a more lethal fighting force and one that is able to operate in austere combat environments envisioned in the 21st century.

> The current and future operating environment requires an expeditionary mindset geared toward increased efficiency and reduced consumption, which will make our forces lighter and faster. We will aggressively pursue innovative solutions to reduce energy demand in our platforms and systems, increase our self-sufficiency in our sustainment, and reduce our expeditionary foot print on the battlefield. (USMC Expeditionary Energy Office 2011, 5).

The USMC has seen its dependence on energy in the battlefield grow in recent years, and consequently, its dependence on fossil fuel has grown as well. As the Marine Corps withdraws from its more recent conventional deployments to places like Iraq and

Afghanistan, it is planning to return to its roots as a fully expeditionary organization. The word expeditionary is defined in Marine Corps Doctrinal Publication (MCDP) 3, Expeditionary Operations, in the following manner:

> The term “expeditionary” also implies austere conditions and support. This does not mean that an expeditionary force is necessarily small or lightly equipped, but that it is no larger or heavier than necessary to accomplish the mission. Supplies, equipment, and infrastructure are limited to operational necessities; amenities are strictly minimized. (HQ USMC, 1998, 35)

The USMC has also acknowledged that during major occupied combat operations in those two theaters, its dependence on liquid fuel and water was a major vulnerability. This dependence on liquid fuel requires their supply lines to be protected and removes forces that would otherwise be able to be engaged in offensive combat operations: “The future security environment requires a mindset geared toward increased energy efficiency and reduced consumption, thus allowing us to operate lighter and faster” (Amos 2010, 9).

E. EXPEDITIONARY ENERGY OFFICE (E2O)

At the direction of the Commandant of the USMC, the Expeditionary Energy Office was established in 2009. This office was given the following mission: “To analyze, develop, and direct the Marine Corps’ energy strategy in order to optimize expeditionary capabilities across all war fighting functions” (USMC Expeditionary Energy Office. 2011, 5).

The tenets of the E2O, Fast, Lethal, and Austere, will be used as guidance for the research into the reduction of the energy footprint of the MEB based on the ship-to-shore connector usage. The efforts of the research are directly tied to the several of the overarching functions of the E2O:

- Lead Change Process
- Sustain Integration and Innovation
- Maintain Vision and Way ahead
- Reinforce New Practices and Learning
- Develop Success Measures. (Charette 2012, 2)

The E2O office has identified changes in doctrine, training, organization, and leadership as the way to effect a 25% reduction in fuel consumption by the year 2025. Based on the inputs from the E2O stakeholders, the capstone team will focus its research the mission of the E2O through in accordance with its overarching functions. In order to accomplish this, the team must first understand the current methodologies that are employed during amphibious warfare by the USMC.

F. STAKEHOLDERS AND STAKEHOLDER INPUT

The primary stakeholder of this capstone project is the USMC E2O. The E2O office can be assumed to include the Amphibious Warfare community and its associated commands and personnel. The expected deliverable for the E2O and the USMC Amphibious Warfare stakeholders is a report suggesting strategies to reduce the energy footprint of the MEB without sacrificing mission readiness and capabilities.

In addition to the strategies for energy reduction, these stakeholders will also receive input on areas to perform additional research that the team uncovered during its research. These areas were either deemed out of scope or unable to be evaluated during the time allotted; however, they may be worthy of further research to the E2O.

The secondary stakeholders include the Systems Engineering (SE) Department at Naval Postgraduate School, the faculty and chair of the SE Department, and the commands from which the students originated. The deliverable for these stakeholders includes the capstone report, which is a requirement for graduation, two interim progress reports, and a final project briefing. The USMC stakeholders will also receive these progress reports and the final briefing.

The team initially met with met with representatives from the E2O to determine the scope of the mission that was to be researched. The team met with Gayle von Eckartsberg, Deputy Director, U.S. Marine Corps Expeditionary Energy, on 23 April 2013, to have a briefing about the current issues involving the expeditionary energy footprint of the USMC. The following broad instructions were brainstormed by the E2O to the capstone team for its project.

- Build new methodologies: Consider altering current thinking and doctrine.

- Explore the feasible: Remember to limit research to current capabilities.
- Push the academic side: Use SE methods and skills to push into area not known first hand by the group. While lacking the practical expertise on the topic, this will give the group an unbiased opinion of possible options for and results of the research.
- Ask broad questions about changes how in doctrine could affect energy use. Do not be afraid to challenge convention and look at the bigger picture when considering the problem.

Throughout the conversation, the E2O stressed the ship-to-shore connector efficiency was of particular interest in addition to putting emphasis of research on the "Assault Phase" of the operation.

Through the interface sessions with the stakeholder, the team was able to identify the primary stakeholder objectives for this research project:

- Maintain Mission effectiveness while performing an A2/AD Amphibious Assault
- Reduce MEB energy footprint while performing an A2/AD Amphibious Assault

The stakeholder's objectives will be used to translate the operational needs of the stakeholders into quantifiable measures that can be used as a basis of comparison between different ship-to-shore connector configurations, which will result in different solution sets.

G. RESEARCH QUESTIONS

Based on this input from our primary stakeholder, the USMC E2O, this report studies the energy consumption of the MEB as currently assembled. The research will focus on answering:

- Can improved fuel efficiency be reached through changes in DOTMLPF while maintaining mission capability?

Additionally, this research will seek to determine whether the following secondary questions can be answered:

- What particular connectors have the most effect on fuel efficiency?
- Can the environment affect the ability of the MEB to achieve better fuel efficiency?

The report examines solutions to these questions by varying the amount and types of connectors (ships or aircraft that deliver personnel and equipment from large amphibious ships to shore) used during an amphibious operation in addition to exploring possible exchanges of DOTMLPF and capability/force size to accomplish the mission.

This report and strategies are based on the research of the cohort and address changes in doctrine, organization, training, materiel, leadership and education, personnel or facilities and policy.

> DOTMLPF-P is the DoD acronym that pertains to the eight possible non-materiel elements involved in solving war fighting capability gaps. These solutions may result from a Capabilities-Based Assessment (CBA) or any study that investigates DoD war fighting capabilities and identifies capability gaps. (Defense Acquisition University 2013, 1)
>
> DOTMLPF-P stands for:
>
> - Doctrine: the way we fight (e.g., emphasizing maneuver warfare, combined air-ground campaigns)
> - Organization: how we organize to fight (e.g., divisions, air wings, Marine-Air Ground Task Forces)
> - Training: how we prepare to fight tactically (basic training to advanced individual training, unit training, joint exercises, etc.).
> - Materiel: all the "stuff" necessary to equip our forces that DOES NOT require a new development effort (weapons, spares, test sets, etc., that are "off the shelf" both commercially and within the government)
> - Leadership and education: how we prepare our leaders to lead the fight (squad leader to 4-star general/admiral – professional development)
> - Personnel: availability of qualified people for peacetime, wartime, and various contingency operations
> - Facilities: real property, installations, and industrial facilities (e.g., government owned ammunition production facilities)
> - Policy: DoD, interagency, or international policy that impacts the other seven non-materiel elements. (Defense Acquisition University 2013, 1)

Measures of Effectiveness (MOEs) are established from the architecture of the existing MEB so that a fair comparison may be made to the future brigade make up. The MOEs will focus on the areas of fuel consumption on the battlefield and mission effectiveness.

Using systems engineering methods, various changes to the ship-to-shore operations of the MEB were explored and modeled, which resulted in identifying parameters that were influential on reducing energy consumption. These parameters include the number of amphibious platforms, timing of ship-to-shore operations, and quantities of ship-to-shore connectors used to perform the landing. Additional consideration is given to the most effective suggestions when seeking to increase efficiency. It is important to note that not only is an increase in efficiency important, but more important is the question of added capabilities derived from increased efficiency and the maintaining of mission readiness.

H. SCOPE

The initial input for the body of work was derived from the Expeditionary Warfare 2012 (EW12) exercise, discussed in Chapter III.B.1.a. Given that the amphibious operations of a MEB are very complex, the Cohort had to place restrictions on the study of the MEB operations in order to be able to complete the research in the allotted period of time. These scoping restrictions on research were vetted with the advisors and the E2O stakeholders prior to the initiation of the research.

Elements that were considered to be out of scope of the research of this project were termed Phase I–Assemble the MEB and Phase III–Sustain the MEB. These operations, although equally as important to the success of the amphibious assault, were not evaluated for improvements in energy efficiency. Phase II of EW12 is described in the introduction of MCWP 3-31.5 as the "Assault Phase"; the phase focusing on the use of the ship-to-shore connector fleet to deliver the combat and logistics forces from the seabase to their objectives.

The consumption of energy by the MEB forces, specifically the fuel consumption of the connectors, vehicles, and troops are the primary focus of the modeling and new

proposals. Although the modeling focus on the current make-up of the USMC amphibious ship-to-shore connectors and ships, the team varies the parameters of these connectors (range, speed, fuel efficiency, and payload) in order to make proposals for improvements to the current fleet. Additionally, opportunity may exist for evaluation of commercial-off-the-shelf (COTS) alternatives that are in existence.

Other areas of reduction in energy consumption were also out of scope to the research, including improvements in generators, batteries, or fuel efficiencies gained by improved fuel economy or type. These improvements merit further study but were not considered in scope of this project.

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II. AMPHIBIOUS OPERATIONS

A. BACKGROUND

1. Amphibious Warfare

The USMC is designed as a force that has combat units that are manned and ready to deploy to conflict situations around the world. Due to its alignment under the Department of the Navy, the USMC operates and deploys from USN ships. The relationship allows the USMC to be highly mobile and to deploy to any area that has access to the oceans of the world. The Marine Corps Doctrinal Publication (MCDP) 3, Expeditionary Operations, states:

> The Marine Corps as an expeditionary force-in-readiness that is manned, trained, and equipped specifically to respond quickly to a broad variety of crises and conflicts across the full range of military operations anywhere in the world. It emphasizes the naval character of Marine Corps forces. This naval expeditionary character provides capabilities both to forward-deploy forces near the scene of potential crises as well as to deploy sustainable, combined arms teams rapidly by sea and air. (Foreword)

As such the USMC is frequently tasked to take on many non-military operations for which its unique ability to mobilize from the sea makes it the best tool for the job. These operations include humanitarian aid missions and operations to provide disaster relief.

2. USMC Organization

The USMC organizes itself into commands associated with their geographic area. The three force commands are Marine Corps Forces Atlantic (MARFORLANT), Marine Corps Forces Pacific (MARFORPAC), and Marine Corps Forces Reserve (MARFORRES). These commands are accountable to the Commandant of the USMC and provide support to their expeditionary forces (HQ USMC 1998, 65).

a. USMC Amphibious Organizational Structure

The hierarchy of the expeditionary structure in the USMC starts with the Marine Expeditionary Force (MEF) which is the largest deployable force in the USMC. The standing MEFs are:

- I Marine Expeditionary Force in California and Arizona (MARFORPAC)
- II Marine Expeditionary Force in North and South Carolina (MARFORLANT)
- III Marine Expeditionary Force in Okinawa and Hawaii (MARFORPAC)
- 4th Marine Division, 4th Marine Aircraft Wing, and 4th Force Services Support throughout the United States (falls under the USMC Reserve).

The MEF will support a MEB with troops, training, and equipment, which can be deployed as part of contingency operations or to a major theater of war. The MEB is scalable to adjust to the force size needed to accommodate the mission, typically between 4,000 and 16,000 Marines. Typically a MEB contains sufficient supplies to operate independently for up to 30 days (HQ USMC 1998, 74). The standing MEBs are:

- 1st Marine Expeditionary Brigade at Camp Pendleton, CA
- 2nd Marine Expeditionary Brigade at Camp Lejeune, NC
- 3rd Marine Expeditionary Brigade at Camp Courtney, Okinawa

The MEBs are subordinate to I MEF, II MEF, and III MEF, respectively. The MEB typically operates from an organization of ships called an ARG.

b. Expeditionary Warfare

The USMC utilizes the nomenclature of Marine Air-Ground Task Force (MAGTF) for the organization of its mission oriented combat force (HQ USMC 1998, 69). The MAGTF is mission oriented in that the collection of elements that makes up its troops, vehicles, and equipment is tailored to the mission at hand:

> Most military organizations are specifically designed for particular missions, and reorganization tends to reduce their effectiveness. However, the Marine Corps' building- block approach to MAGTF organization makes reorganization a matter of routine. Tailoring MAGTFs for specific missions through task organization is standard procedure. (HQ USMC 1998, 69)

The USMC trains to deploy its forces in a MAGTF so that the organization, tasks, and functions used in its operations are well practiced and standardized. The MAGTF is organized into four major elements (Figure 1).

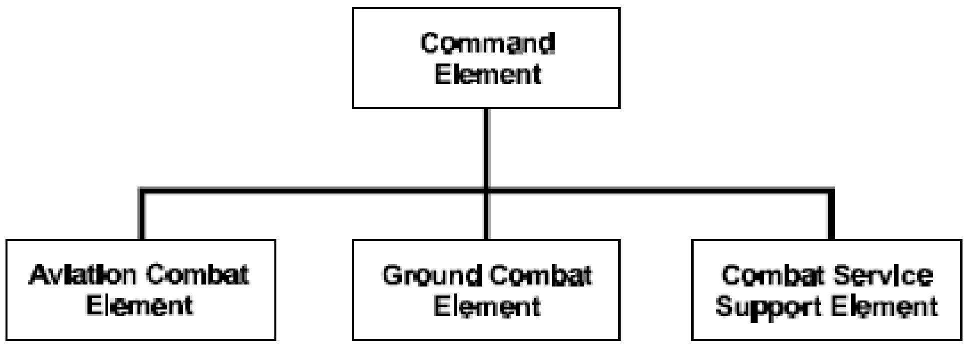

Figure 1. The principal elements of the MAGTF include the Command Element (CE), the Aviation Combat Element (ACE), the Ground Combat Element (GCE), and the Combat Service Support Element (CSSE) (from HQ USMC 1998, 71).

The Command Element (CE) includes command and control functions, intelligence, and some supporting functions such as administration activities. The Ground Combat Element (GCE) performs the ground combat operations of the MAGTF and is composed of infantry, artillery, reconnaissance, and armor units. These are supported by engineering units as needed along with transportation and support furnished from the Aviation Combat Element (ACE) and USN landing craft. The GCE, with the other elements, is scalable to the requirements of the mission. The ACE provides the aviation elements to perform the following functions:

- Anti-air warfare
- Assault support
- Offensive air support
- Air reconnaissance
- Electronic warfare
- Control of aircraft and missiles

The ACE is not a support unit of the GCE, but rather an equal element of the MAGTF, whose utilization is directed by the CE. The ACE can operate from the seabase ships or may transition to land bases during operations. These bases can include expeditionary airfields, forward operating locations, and existing aviation infrastructure. The final element of the MAGTF is the Combat Support (CSSE). The CSSE is responsible for supporting the MAGTF logistically during the operation. This support can be conducted from the seabase and shore locations such as the Beach Support Area (BSA) or an expeditionary base (HQ USMC 1998, 72).

B. THE AMPHIBIOUS ASSAULT

The USMC stages the MAGTF from a fleet of special purpose ships that are able to be tailored to various missions. The ships provide everything that the MAGTF needs to perform the amphibious assault. They transport and house the Marines, their weapons and equipment, the vehicles used during the assault, and serve as forward mobile base of operations during the assault (Figure 2). The ship classes have very different designs that are purpose built to support a particular aspect of the MAGTF's needs.

Figure 2. The seabase concept is clearly demonstrated showing the ARG and the wide variety of ship-to-shore connectors in action, sustaining the fight from out at sea (from United States Marine Corps 2011, "How We Seabase").

1. Amphibious Ready Group: Ship Input Parameters

The seabase consists of the ARG ships. The following ship classes are primarily considered for this report.

The Wasp Class Landing Helicopter Assault Ship (LHA) and the Tarawa Class landing Helicopter Dock Ship (LHD), both resemble aircraft carriers in appearance with their main purpose being transporting landing craft and equipment, as well as launch and recover of helicopters, Vertical Take-Off and Landing (VTOL), and Short Take-Off and Vertical Landing (STOVL) aircraft (Commander Naval Surface Force 2013, Wasp class Multiple Purpose Amphibious Assault Ship).

Whidbey Island Class and Harpers Ferry Class Dock Landing Ship (LSD) classes were designed to transport and launch amphibious landing craft and amphibious assault craft (Commander Naval Surface Force 2013, Dock Landing Ship). The Austin Class and San Antonio Class Landing Platform Dock Ship (LPD) classes fulfill the role of the LSD as well as provide a secondary aviation platform for an ARG (Commander Naval Surface Force 2013, SURFPAC's Amphibious Transport Dock (LPD/LPD17) Info Page).

Specific ships are evaluated in this report with respect to the number of landing craft they can carry at once, the number of helicopters they can simultaneously launch and recover, and the dimensions of their well deck. Further details about the amphibious classes of ships can be found in Appendix A. The most important parameters of the amphibious assault ships are shown in Table 1. Each of these parameters is crucial to planning for combat, but not all of them were necessarily helpful to model the ship-to-shore connector network.

Table 1. The most influential parameters of the amphibious assault ships.

Amphibious Ship Parameters
Helicopter Spots
QTY LCACs
QTY LCUs
QTY AAVs
Cargo (TONS)
Troop Capacity

This collection of ships will contain the required number of amphibious ships to carry out the functions of the ARG. These include:

- transportation and storage of the MAGTF equipment and supplies
- embarking/launching ship-to-shore surface connectors for the GCE
- embarking/launching ACE (fixed and rotary wing)
- command, control, communications, computers, and intelligence (C4I) platform for surface, subsurface, and air units assigned to the ARG
- medical services. (Marine Corps Combat Development Command, 2001, 1–21)

As the MEB composition varies with the required mission, the ARG carrying the MAGTF also varies. Considering this, the number of amphibious ships was omitted from the modeling in order to allow different combinations of ship-to-shore connectors. This omission in the modeling allows the identification of parameters for the ship-to-shore connectors that contribute the most towards energy efficiency.

In a similar scenario, the capstone team will also be fixing the required equipment for the MAGTF. This has been done under consideration of the Expeditionary Warfare 2012, which this A2/AD mission was designed around, and in conjunction with USMC training doctrine, as well as, USMC personnel.

The ships of the amphibious fleet are incredibly varied in their capability and configuration. Accounting for this variation in the modeling effort will be crucial to both assessing the current state and proposing any changes to the utilization of the connector fleet. The variation manifests itself in several different ways for the ships.

a. Amphibious Ship Well-Deck Dimensions

The amphibious ship parameter of well deck capacity for the ship-to-shore connectors is one of the most crucial parameters when determining the throughput of the ship in a ship-to-shore landing operation. Consequently, the ship's well-deck designs vary greatly. The well decks are designed to service, load, and launch the surface-borne ship-to-shore connector fleet of the USMC. These connecters include LCUs, LCACs, Amphibious Assault Vehicles (AAVs), and can also include the Landing Cushion Mechanized (LCM-8) boats. These surface-borne ship-to-shore connectors are discussed further in Chapter II C 2.

The LHA and LHD have rather large well decks; however, the central island of the LHA prohibits it from embarking more than one LCAC at a time. This is not an impediment when the LHA embarks LCUs. The LCUs are narrow enough to sit on either side of the central island and it can embark a total of four. These options of one LCAC or four LCUs are mutually exclusive of each other. The LHD can embark either three LCACs or two LCUs.

The remaining ships in the fleet can generally embark one or two of either an LCAC or LCU. The exception to this is the LSD-41 class, which can embark a total of four LCACs or three LCUs. This is due to its cavernous internal well-deck length of almost 450 feet, the largest in the fleet. The ships of the LSD-41 class and the subsequent LSD-49 class were designed with the use of LCACs in mind. They have integrated administrative and support facilities to embark and deploy the LCACs. When LCACs deploy from the other ships of the amphibious fleet, they are required to have MILVANS installed to provide the minimum level of logistics support to the LCAC fleet (Headquarters, U.S. Marine Corps, 1997, 1–3).

A chart showing the well deck dimensions and the landing craft/helicopter spot capability for each ship is shown in Figure 3 and Figure 4 (Marine Corps Combat Development Command, 2001, 1–23).

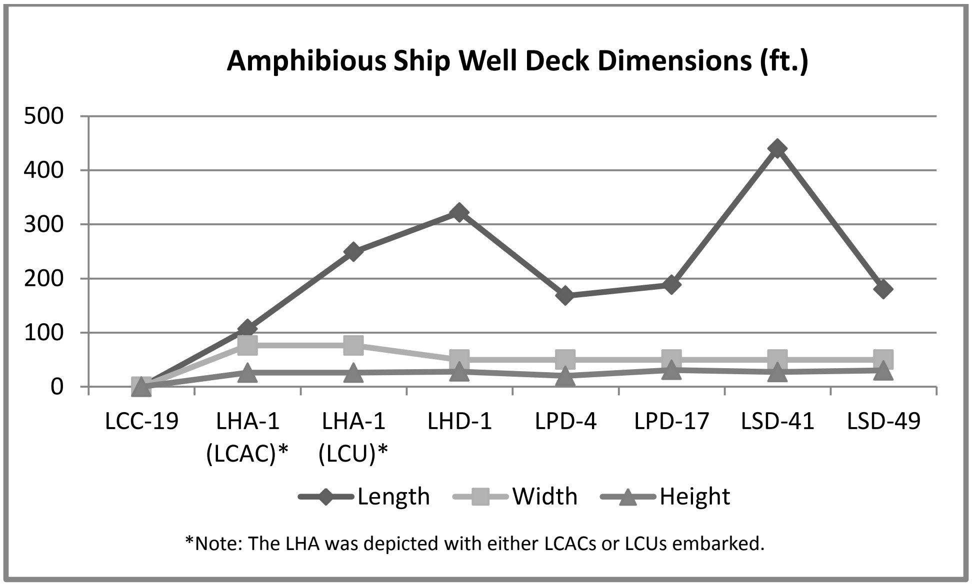

Figure 3. The dimensions of the well deck in feet are shown for each amphibious ship.

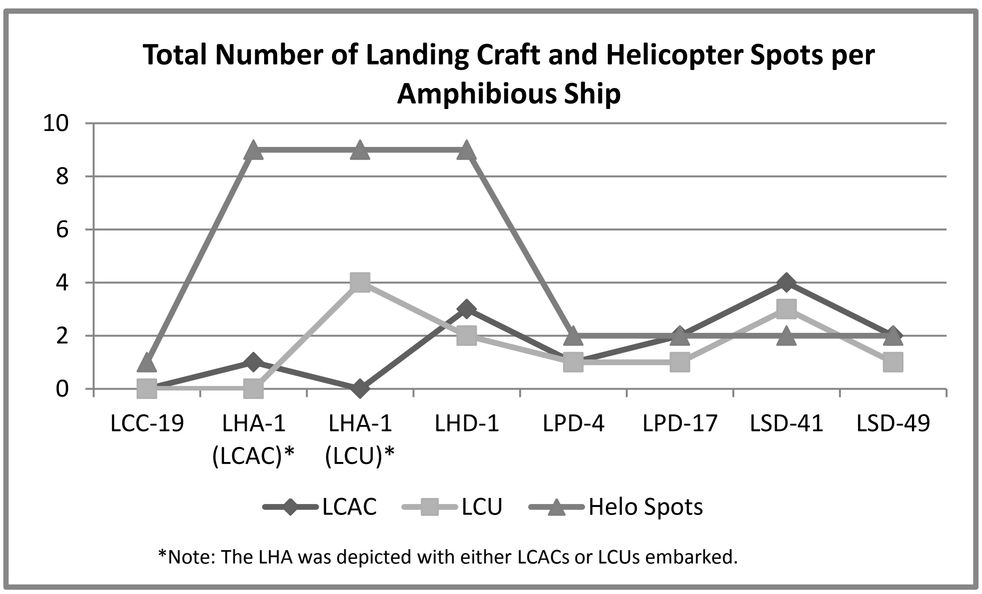

Figure 4. The number of landing craft and helicopter spots is shown for each amphibious ship.

b. Troop Capacity

The troop lift capacity will be a major variable in the modeling of the MEB. The MEB typically has available approximately 14,000 to 16,000 troops to embark. The MEB is scalable to the mission at hand and can be comprised of troop strengths of anywhere from 4,000 troops for an amphibious MEB to 16,000 troops when taking advantage of pre-positioned supplies (Global Security 2013, 2).

The amphibious ships studied are able to transport groups of troops in two major sizes. The LHA and LHD classes can carry roughly 2000 Marines in addition to the crew. The LPD and LSD classes can carry between 500 and 800 Marines in addition to the crew, depending on the vessel (Marine Corps Combat Development Command, 2001, 1–23).

c. Aviation Support

Although each of the major ships in the amphibious fleet are able to support aviation operations, there are several ships that are configured with more priority to given to space for aviation activities and aviation fuel. The LHA and LHD class are able to operate helicopters and some fixed-wing assets from nine spots on the helicopter deck. The remaining ships in the fleet have two spots from which to operate helicopters from.

The LHA and LHD also have the largest amount of JP-5 fuel reserves available to support aviation operations, at roughly 400,000 gallons. The LPD class carries roughly 250,000 gallons and the LSD class ships have less than 100,000 gallons of JP-5 to support aviation (Marine Corps Combat Development Command, 2001, 1–23).

d. Cargo and Vehicles

The LHA and LHD classes far surpass the other ships with their ability to carry large amounts of cargo and vehicles. The LHA and LHD classes have roughly 25,000 square feet dedicated to transporting vehicles. The LPD-17 class also has the same amount of space dedicated for vehicles. The LSD-49 and LPD-4/LSD-41 each have

20,000 and 15,000 square feet for vehicles, respectively (Marine Corps Combat Development Command, 2001, 1–23).

2. Landing Craft

The USMC operates landing craft that have the function of transporting the troops, cargo, and vehicles from the amphibious ships to the shore. These landing craft are generally of two types, those with a displacement hull and those with an air cushion. The two different types have substantially different performance, terrain requirements, and operating concepts.

a. LCAC

The LCAC (Figure 5) is a ship-to-shore connector that rides on a cushion of air. It has the capacity to lift a nominal 60-ton cargo load and a 75-ton load in the overload condition. Each of the amphibious ships can carry between 1 and 4 LCACs in their well decks.

Figure 5. LCAC shown loaded with vehicles and cargo as it prepares to enter the well deck of an amphibious ship. Photograph by Photographer’s Mate Airman Sarah E. Ard, U.S. Navy. Retrieved from *Wikipedia*.

The LCAC is able to transit from 100 miles out to sea at speeds approaching 40 knots. It is able to overcome obstacles up to 4 feet high and does not require a beach to land on. The LCAC is able to operate from over the horizon, allowing the amphibious ships to exploit maneuver in the sea to gain tactical advantage on the battlefield. Drawbacks of the LCAC include limited space for troops to embark without special protective compartments, speed limitations from sea states higher than 3, and high fuel consumption rates.

b. LCU

The Landing Craft Utility (LCU) is the largest of the ship-to-shore connectors. This is a displacement landing craft with ability to carry 400 troops or 143 tons of cargo. It has a speed of 12 knots underway and a range of 1200 miles. The LCU complements the LCACs high speed with a large cargo capacity (Figure 6).

Figure 6. An LCU showing the capability to lift up to 400 troops or greater than 143 tons of cargo. Photograph by Photographer's Mate 3rd Class Travis M. Burns, U.S. Navy. Retrieved from *Wikipedia*.

Unlike the LCAC, the LCU must off load at a beach and this limits the number of places it can discharge troops and cargo. It has a bow and stern ramp to allow roll-on-roll-off (RO-RO) cargo throughput.

3. Ground Combat Vehicles

The first waves of the ship-to-shore connectors will contain the vehicles of the MEB. These vehicles and their crews will enable to the rapid build-up of combat effective forces at the surface landing zones. The fleet is composed of tracked vehicles, wheeled vehicles, towed artillery, trucks, trailers, and associated Materiel Handling Equipment (MHE).

a. Tracked Vehicles

The tracked vehicles make up the majority of the maneuver capability of the MEB. The primary troop transport vehicle is the Amphibious Assault Vehicle (AAV). The AAV can carry 21 troops and self-deploy from the amphibious ships (Figure 7). It has a speed of 6 knots in the water and 25 mph on land. It can also be carried ashore by the LCAC and LCU (MAGTF Staff Training Program, 1999, 2–3).

Figure 7. An AAV leaving the ramp of an amphibious ship. Photograph by Journalist Seaman J.J. Hewitt, U.S. Navy. Retrieved from *Wikipedia*.

The USMC uses the M1A1 Abrams Main Battle Tank (MBT) as its primary anti-armor weapon system. The Abrams weighs approximately 70 tons and is

one of the heaviest vehicles that must be transported from ship-to-shore during an amphibious landing (MAGTF Staff Training Program, 1999, 2–3).

The remaining tracked vehicles include are primarily support vehicles for the MEB. The M88-A1 tank retriever vehicle is necessary for retrieving incapacitated tanks and tracked vehicles. The JOINT ASSAULT BRIDGE (JAB) will be replacing the AVLB, which is a self-transportable combat bridging system (MAGTF Staff Training Program, 1999, 4–49). The engineering team will also utilize the D-7G medium tractor, which functions as a bulldozer. These vehicles will be required when the MEB deploys with heavy tracked vehicle (MAGTF Staff Training Program, 1999, 4–82).

b. Wheeled Vehicles

The wheeled vehicles of the MEB provide it with the ability to conduct maneuver warfare when on land. These vehicles are essential to the MEB's ability to deploy to austere environments and still be combat effective.

The primary wheeled armored vehicle is the Light Armored Vehicle (LAV-25). The vehicle can employ a 25 mm gun or an Electronic Warfare (EW) suite.

The main utility vehicle is the venerable High Mobility Multi-Mission Wheeled Vehicle or HMMWV. This vehicle has many different variants; among which are weapons, ammunition, troop transport, and mobile command post.

The MEB utilizes several variants of trucks for transportation and support services. These are based on the 5-ton and 7-ton truck frames and perform missions such as dump truck, cargo truck, wrecker, and ammunition transport. The other truck in use is the Logistics Vehicle System (LVS) family of trucks. These are able to be configured with flatbed trailers, SIXCON fuel or water distribution systems, or ammunition and cargo transports (MAGTF Staff Training Program, 1999, 2–5).

The necessity of planning to include these wheeled vehicles cannot be understated. The amphibious operational environment is one in which the USMC must bring everything that it needs to support combat, or run the risk of threatening mission success.

c. *Engineering and Support Vehicles*

The operations of the MAGTF require many specialized vehicles that perform various combat engineering functions. The GCE and CSSE employ vehicles such as rough terrain Materiel Handling Equipment, road graders, and cranes. These vehicles are often based on commercial off-the-shelf derivatives, adapted for USMC use. The need for these vehicles becomes apparent when examining the vast infrastructure that is required to support the MEB ashore for missions up to 30 days in length. Requirements are generated for the construction of fuel and ammunition storage facilities that need these heavy duty vehicles to complete.

d. *Aircraft*

The aviation fleet of the USMC reflects its amphibious roots and the need to operate from austere environments. These mission requirements manifest themselves in design decisions like the ability to operate from either very short runways or vertical takeoff capability, as in the MV-22, AV-8B Harrier, and the F-35B STOVL attack aircraft. The USMC also depends on a rugged fleet of rotary winged aircraft that are able to operate as easily from ships or expeditionary airfields. The USMC also uses a variant of the C-130 for cargo transportation and to extend the range of its larger helicopters and fixed-wing aircraft with inflight refueling.

The USMC also operates the F-18E/F multirole fighter, but since this weapon system generally operates from an aircraft carrier or a fixed airbase, it is not a factor when assessing the impact to the ship-to-shore connector system with respect to the use of energy.

e. *Fixed-Wing Aircraft*

The USMC uses fixed-wing aircraft primarily for aerial attack missions and to transport large amounts of cargo over long distances. The attack aircraft include the AV-8B Harrier II and the F-35B Lightning II variant of the Joint Strike Fighter. These aircraft will operate either from the large decks of the amphibious ships (LHD/LHA) or from expeditionary airfields set up by the MAGTF. They have the ability to refuel

inflight from the KC-130 extending their combat range and loiter time. These aircraft are for organic Close Air Support (CAS) missions dictated by the CE of the MAGTF. The KC-130 is the USMC version of the C-130. This aircraft is sued to perform aerial refueling missions and deliver cargo. The aircraft can also serve to offload fuel at the expeditionary air field or with special refueling equipment installed, distribute fuel to helicopters at a Forward Refueling Re-arming Point (FARP). The KC-130 can land at austere locations, but typically is supported at an airfield, either existing (such as a friendly foreign nation) or an expeditionary airfield set up by the MAGTF (Marine Corps Combat Development Command 2005, 3–6).

f. Rotary-Winged Aircraft

The USMC is at the forefront of receiving radically enhanced capability for the full spectrum of its rotary-winged fleet. The legacy helicopters are all being enhanced and the addition of the MV-22 is bringing orders of magnitude improvement to the ability of the amphibious fleet's ability to project power ashore.

The MV-22 is a tilt-rotor aircraft which is slated to replace the retiring CH-46 helicopter. The MV-22 is neither a helicopter nor a fixed-wing aircraft, but operates in both configurations. The MV-22 is able to transport 24 combat-loaded troops, 20,000 LBS or internal or 15,000 LBS of external cargo. It can transport troops up to 200 NM and carry cargo up to 50 NM. It can travel at speeds up to 240 KIAS with troops. It is an enormous increase in capability from the legacy troop carrier, the CH-46 Sea Knight it is replacing. The MV-22 is the primary method to rapidly insert troops in an amphibious assault (V-22 Osprey Program, 2012, 7).

The CH-53E is the largest helicopter in the USMC inventory. This helicopter can carry 24 combat-loaded troops or 20,000 LBS of cargo internally. It can also carry 32,000 LBS utilizing a sling loaded configuration. It has a cruise speed of 135 KIAS and can operate for 4 hours. Its capabilities will be enhanced even further when the new CH-53K enters Initial Operational Capability (IOC). The CH-53 is the primary cargo mover of the aviation ship-to-shore connector network (Marine Corps Combat Development Command 2004, H-3).

The H-1 family of helicopters serves the USMC in both utility and attack configuration. The UH-1 family is a utility helicopter based on the UH-1 Iroquois or 'Huey.' This helicopter can carry 2,000 LBS in a sling or 4 combat loaded troops. It has a speed of 115 knots and endurance of approximately 1.5 hours. The attack configuration, the AH-1 Cobra, carries weapons only and provides close air support for the Ground Combat Element (GCE) (Marine Corps Combat Development Command 2004, H-4).

4. MEB Equipment and Provision Considerations

The cargo and equipment that the MEB requires to conduct sustained operations of 30 days was researched by the capstone group for the intended purpose of defining the task that is to be performed by the ship-to-shore connectors. The MEB requirements have been determined through extensive use of Marine Corps Doctrine and using the EW12 scenario as a backdrop to provide the A2/AD mission requirements. Additionally, a Back of the Envelope (BOE) Model was built by the team using these inputs to determine minimum requirements for the MEB to land and sustain itself ashore.

Table 2. The home screen showing the input controls of the Back of the Envelope (BOE) model, which is designed to rapidly allocate airborne and surface landing craft to a specific set of amphibious assault ships. The quantities of connectors can be rapidly changed and are added up by ship class (horizontally) and connector type (vertically).

QTY	Ship VEH SF Capacity	CONN Weight CAPP	CONN Area CAPP / Ship Type	Fuel (GAL) / wave	Time (hour) / QTY / Wave	LCAC K	LCU J	CH-53K H	MV-22 G	UH-1Y I	ime our) / Vave	LCAC K	LCU J	CH-53K H
1	3015	14500	0	1969	1.340	0	0	0	1	1	**2**	0	0	0
0	28700	0	Assault LHA-1 0	0	4.369	1	0	3	4	0		1	0	3
0	24000	0	0	0	4.733	3	0	3	3	0	**6**	3	0	3
1	25000	572000	3700	1737	2.895	0	2	0	0	0	**2**	0	2	0
0	14000	0	Trans Dock LPD-4 0	0	0.000	0	0	0	0	0		0	0	0
1	11831	562000	7236	4522	2.572	4	0	0	0	1	**2**	4	0	0
1	20000	280000	3618	2084	0.868	2	0	0	0	0	**2**	2	0	0
4			**Tota**	**Total CON/Ship**		**10**	**2**	**6**	**8**	**2**	**14**	**10**	**2**	**6**

Table 3. The result of the BOE is the amount of cargo that can be carried by the chosen set of landing craft. This allowed the team to calculate changes to the set of ships very rapidly and estimate the cargo capacity of the connectors. This is shown per ship class and also totaled in Table 4.

Ship Type	QTY	Ship VEH SF Capacity	CONN Weight CAPP	CONN Area CAPP	Fuel (GAL) / wave	Time (hour) / Wave	LCAC K	LCU J	CH-53K H
Command	1	3015	14500	0	1969	1.340	0	0	0
Assault LHA-1	0	28700	0	0	0	4.369	1	0	3
Assault LHD-1	0	24000	0	0	0	4.733	3	0	3
Trans Dock LPD-17	1	25000	572000	3700	1737	2.895	0	2	0
Trans Dock LPD-4	0	14000	0	0	0	0.000	0	0	0
Dock Landing LSD-41	1	11831	562000	7236	4522	2.572	4	0	0
Dock Landing LSD-49	1	20000	280000	3618	2084	0.868	2	0	0
Total Ships	4				Total CON/Ship		10	2	6

Table 4. A sample of typical results from the BOE allowing the team to rapidly make changes to the connector fleet configuration and estimate some of the major effects right away, such as number of waves needed, fuel efficiency of the connector fleet, or throughput of cargo. It should be noted that these figures are not completely realistic as many factors are unaccounted for, but this tool was helpful for order of magnitude calculations to estimate the gross value for figures of interest.

CONN Fuel per round trip	**10312**
Total LIFT Cargo LBS	**1428500**
Total hours cargo to objective	**17**
Total LCAC ARG	**6**
Total LCU ARG	**2**
Total MV-22	**1**
Total CH-53K	**0**
Total UH-1Y	**2**
Waves Needed	**26**
VEH Distance Traveled/day	**100**
ARG to VEH DIST	**125**
ARG to Beach DIST	**20**
Fuel Efficiency (LBS/GAL) 138.5	**Cargo (LBS/Hour) 85144**

The three main areas of focus consisted of equipment, fuel, and provisions for MEB personnel. These findings are to provide a realistic weight and footprint of the effort the connectors will undertake for the modeling process.

The BOE was used to provide inputs to the model as to the number of tons of vehicles, fuel, and provisions necessary to conduct an engagement of the size that was being modeled. The following subsections will discuss the assumptions made and resources used to provide input data for the simulation. A complete table of equipment and provision numbers is provided in Appendix B. Scaling MEF numbers down to a MEB sized Task Force has given the capstone group a place to start. The model effort is scalable to meet force size requirements for different scenarios.

a. MEB Vehicles and Equipment

The comprehensive list of combat equipment, supplies, and support equipment are located in Appendix B. This list was assembled by the team and was based primarily on information obtained from USMC doctrine manuals and literature regarding the types of equipment needed for a MEB sized MAGTF. The initial elements of the combat force (CE, GCE, ACE, and CSSE) were sized to approximate the number of troops needed to accomplish missions of the type that described in the EW12 exercise, described in III.B.1.aA

Once the assumptions for size of the combat forces were decided, the vehicles, support equipment, food, fuel, and water requirements could be derived with a relative degree of accuracy. It is important to note that model inputs drove the need for values for these categories. Given that the team members are not professional USMC infantry or logisticians, the values may not be precise enough to plan combat operations, but they are precise enough to run a model simulating ship-to-shore operations for a specified amount of tonnage, and are useful in that aspect alone.

b. Fuel Requirements

Each piece of equipment that requires fuel, from a generator to M1A1 tank was given consideration for their fuel needs. Once the complete list of vehicles and

equipment was complete, shown in Appendix B, the totals were obtained by adding up the daily requirements needed for each vehicle, towed piece of equipment (which drove a requirement for a Prime Mover), powered equipment such as a water purifier or generator, and engineering equipment. Nominal distances that would be expected to be encountered, based on the EW12 scenario, were used to effect fuel consumption among the vehicles.

GPH was chosen as the unit of energy consumption to be used in the modeling process. It was the most common unit presented in the reference material or was easily able to be derived based on fuel capacity and range of a vehicle. The GPH unit was also used in the Marine Air-Ground Task Force (MAGTF) Power and Energy Model (MPEM), a spreadsheet that was provided to the capstone group by the E2O as a reference of previous efforts to study energy consumption and highlight inefficiencies in the MEB.

c. Food and Water

The number of personnel needed to perform a MEB sized operation was used in order to determine the tonnage required for food and water planning. Based on the manning for the equipment chosen to best represent an A2/AD MEB and the objectives of EW12 we determined the MEB would consist of approximately 10,000 personnel.

Part IV (Staff Planning Factors and Considerations) of the MEF Planner's Reference Manual allowed an estimate amount of food in tons and water in gallons per day that needed to be brought ashore per person. The amount of water estimated to be needed delivered or produced was based on a rate of consumption of 8.9 gallons per troop per day using tropical zone factors (MAGTF Staff Training Program, 1999, 4–75). The amount of water that would need to be purified and then transported over land to personnel located at the objective was approximately 1.5 million gallons over 30 days.

The food was calculated by using meals ready to eat (MREs) for simplicity. These planning factors for MREs were also obtained in the MEF Planner's Reference Manual (MAGTF Staff Training Program, 1999, 4–74). Three meals a day

were planned for the duration. These quantities approximate actual values used for planning an A2/AD and are sufficiently close to yield results that are useful for analysis.

The quantities of fuel required to transport the food and water ashore, produce water on site, and distribute it all overland to the troops, were accounted for in the total fuel requirement.

5. Current Missions

As the threats have changed, so have the ways the Marine Corps seeks to accomplish the mission. The modern day USMC has acknowledged that the future military and foreign political engagements that will face the United States will likely no longer be a conflict of two major global superpowers. Instead, the USMC is preparing to operate in response to the crises of the 21st century, which are disaster, disruption, and dispute (Headquarters USMC 1998, 5). From Marine Corps Doctrinal Publication 3, p. 6:

- Disasters are accidents or calamities—complex human emergencies—that cause suffering on a massive scale
- Disruptions are intentionally disorderly activities that cause internal commotion on a scale sufficient to interfere with a government's ability to perform its function
- The third class of crisis is dispute, a clash between two political groups.

These crises will likely involve interfacing in regional powers around the world from the littoral areas.

a. Humanitarian Assistance Disaster Response (HADR)

The HADR mission area includes rapid mobilization of forces and supplies to an area affected by natural disaster or internal turmoil. Recent prominent HADR mission include evacuation of Lebanon, assistance to hurricane victims in Haiti and support to survivors of tsunamis in both Thailand and Japan. The HADR mission utilizes that large cargo capability of the Navy's amphibious fleet combined with the Marines ability to establish and secure a landing site to provide and distribute food, water, and aid to the local populace of the affected region.

b. A2/AD Mission

A2/AD is not a single term even though they are often spoken together. Anti-Access challenges refer to long range enemy threats that prevent U.S. freedom of navigation through the global common areas. The threat can be posed by lethal and non-lethal measures. Some non-lethal measure could be political in nature by pressuring our allies to not allow us to operate from our foreign bases, and hostile actions that take place in cyberspace aimed at our ability to coordinate movements globally. Lethal means could include ballistic missiles and submarines (Freier 2012, Section A2 paragraph 2).

The Joint Operational Access Concept (JOAC), describes how operational access will be achieved in the face of an armed opposition under varied conditions: "Area denial refers to those actions and capabilities, usually of shorter range, designed not to keep an opposing force out, but to limit its freedom of action within the operational area" (Dempsey, General Martin E. 2012, i).

The overarching desire set forth in JOAC is "cross-domain synergy" that will usher in joint integration at all echelons (Dempsey, General Martin E. 2012, ii). This unprecedented level of integration will allow operations to flow smoothly and seamlessly through all branches of the military.

c. Joint Operational Access Concept

The JOAC uses broad terms to define the resources and level of integration needed to meet the A2/AD challenges. Those A2/AD challenges are very similar to the EW12 wargame that provides the backdrop for this capstone project. EW12 was

> able to explore operational challenges, potential shortfalls and naval integration opportunities for the Joint Operational Access Concept (JOAC), the Navy and Air Force's Air-Sea Battle Concept and conceptual initiatives from the Marine Corps Amphibious Capabilities Working Group (Wargaming Division, 2012, Executive Summary).

EW12 is different than previous iterations. It was meant to identify gaps and areas of the joint force that need improvement, not as a man to man play-out of a possible war scenario. EW12 will be discussed in greater detail in Chapter III, Section B.

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III. SYSTEMS ENGINEERING PROCESS

A. SYSTEMS ENGINEERING CONCEPTS

The capstone project team uses a Systems Engineering approach to explore variations of the connector network for a MEB. Additionally, the team will use modeling and simulation tools to validate the proposed changes to the current architecture of the MEB during A2/AD operations.

B. REQUIREMENTS ANALYSIS

Given the stakeholder's inputs, the traditional Systems Engineering process was used to decompose the stakeholder objectives into functions that could be allocated into physical components for analysis. This process involves assessing mission requirements, creating an architecture based on system functions, and allocating those functions to physical components. The resulting solution will then be modeled to assess system performance while achieving mission effectiveness.

1. Requirements Traceability

In order to analyze the effects of changes designed to reduce energy footprint on different variants of MEB operations, it was desirable to have a realistic MEB scenario from which to add context and realism to a MEB functional architecture and derive key amphibious warfare capabilities. Rather than creating a notional MEB architecture from which to make comparisons, an existing scenario to enhance the credibility of the functional architecture assumptions was chosen.

a. Baseline Scenario: Expeditionary Warrior 2012

The scenario chosen was EW12, which is a Marine Corps Title 10 Wargame:

> Expeditionary Warrior (EW), the Marine Corps' Title 10 wargame series, is conducted annually by the Wargaming Division of the Marine Corps Warfighting Laboratory to examine issues relating to the future of the force, with representatives from every Service of the U.S. Armed Forces, combatant commands and multinational partners. (Marine Corps Combat Development Command 2013, 13)

The EW12 scenario explores the A2/AD mission, in a fictional nation in Western Africa in the year 2024. Many of the key challenges explored by EW12 were not germane to the interests of this cohort's capstone project, however, the objectives of several of the vignettes explored in EW12 were ideal to use. EW12 explores the wargame by the use of vignettes designed around the allied nation of Savanna being invaded both from within by a political opposition movement and from the exterior by a neighboring nation with hostile intentions. EW12 also provided a rich assortment of terrain features, infrastructure constraints, and large distances to be traveled (Figure 8). This backdrop allowed the cohort to have a credible enemy threat from which to build the MEB architecture for the purposes of exploring methods by which to reduce the energy footprint of the Marine Corps during expeditionary operations.

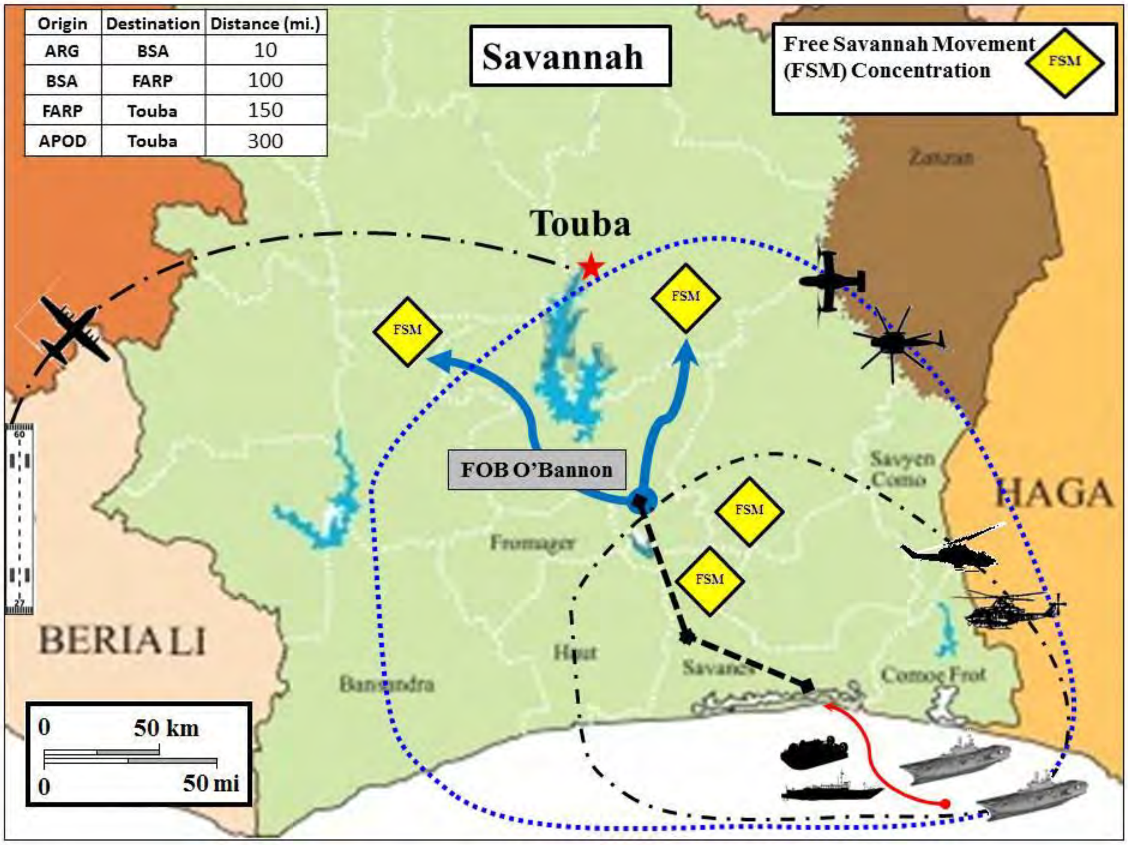

Figure 8. Notional Concept of Operations of EW12 amphibious operations used to illustrate distances for ship-to-shore connector fleet.

b. Measures of Effectiveness

The backdrop of EW12 provides the traceability from the notional architecture to the realistic organization of troops to accomplish a mission. This allowed the team to determine MOEs that would be applicable to use for evaluating both the current structure of the MEB its connectors and any proposals that would make tradeoffs to reduce the energy footprint of the MEB.

The mission of the director of the E2O, as stated by the Commandant of the Marine Corps in the CMC 35 Planning Guidance, is to "develop a plan to decrease the Marine Corps' dependence on fossil fuels in a deployed environment" (Amos 2010, 13).

Against this backdrop, the Capstone 311–122O group generated the following MOEs:

- MOE #1: Throughput of the connector system – Capability of Connectors to transport MEB
- MOE #2: Reduction of fuel consumed by MEB during the conduct of an amphibious assault over a baseline configuration

c. MOE #1: Throughput of Connectors

MOE #1 assesses the capability of the MEB to effectively transition its assets from the ARG ships to the shore, which is traceable to the first stakeholder objective 'Maintain Mission effectiveness while performing an A2/AD Amphibious Assault.' The current state of ship-to-shore operations accomplishes this objective, at the expense of consuming large amounts of fuel to facilitate the operation of the large ship-to-shore network. The trade space of the ship-to-shore network will be explored by modeling the network and introducing changes. The effects of these changes will be captured in MOE #1 as a measure of throughput over a period of time. This MOE was further decomposed into two MOPs:

- MOP #1: Utilization of Service bays at seabase include consideration of:
  - Number of well deck bays available for surface connectors
  - Number of connectors actively serviced
  - The percent of bays that are utilized over time.
- MOP #2: Average delay of connectors waiting to transport MEB

These MOPs contribute to the success of the MOE involving throughput of the connector system. Given the variation of the ships in the ARG, these MOPs are appropriate to be manipulated in the trade space to determine their actual significance regarding the throughput of the connector system. The result of varying these MOPs would translate into real world operational capability by the validation of the current ability to service the connectors or the requirement to increase the number of bays, numbers serviced, or improve the servicing time in the future.

d. MOE #2: Reduction of Fuel

MOE #2 is traceable to the second stakeholder objective, "Reduce MEB energy footprint while performing an A2/AD Amphibious Assault." This MOE accounts for the amount of fuel consumed by the connector fleet in total during the conduct of an amphibious assault. This MOE allows an assessment of the effect of tradeoffs made after any modifications to the configuration of the connector fleet. This MOE is decomposed by one MOP:

- MOP #1: Fuel consumed by connectors during conduct of amphibious assault

The fuel consumption of the connector fleet is as varied as the fleet itself. Monitoring the consumption of the various connectors will allow the effect of tradeoffs on the MOE to be traceable to the variations of the configurations of ship-to-shore connectors that were utilized.

C. ARCHITECTURE

With the creation of MOEs, the next step was to generate a set of appropriate high level functions. This is done through the creation of a functional architecture. The functional architecture was then further decomposed into the physical architecture, from which the physical allocation of components occurred.

1. Creation of an Abstract Functional Architecture from EW12

In order to determine the set of functions that would compose the proposed architecture, the EW12 scenario was closely examined to determine the functional requirements of an A2/AD mission. These functions are high level and somewhat abstract. They are not associated with a particular strategy or specific hardware. Since EW12 was an authentic USMC training exercise, its vignettes were used to help shape the functions that would be required.

a. The Functional Architecture

The functional architecture represents the high level functions and their arrangement, in order to achieve the mission requirements. The stakeholder objectives required that the notional MEB created by the group be able to:

- Maintain mission effectiveness while performing an A2/AD Amphibious Assault
- Reduce MEB energy footprint while performing an A2/AD Amphibious Assault

(1) Scoping the Research. The context for the first objective was determined using the EW12 exercise to supply a realistic mission to draw functions from. EW12 breaks its battles up into three distinct phases:

- Phase I: Achieve Access
  - Establish base at Savannah Islands and establish support for seabase operation
- Phase II: Gain Entry
  - Seizure of a lodgment and the rapid introduction of forces
  - Mount an attack to secure the (fictional) city of Touba
  - Continue to expand the aerial and sea ports of debarkation
- Phase III: Follow-on Operations
  - Support follow-on operations. (Wargaming Division. 2012, 8). The stakeholder objectives require analysis of mission effectiveness while reducing fuel consumption in the connector fleet during amphibious operations. EW12 encompasses much more than those objectives, but the analysis was scoped so that the research of the team would focus only on the functions pertinent to the interest of the stakeholders.

This led to many of the primary functions of an ARG conducting an amphibious assault to be out of scope. These included everything associated with Phase I and Phase III. Phase I: Achieve Access, involves the process of assembling the ARG at in the AOR where the invasion is set to take place. It also focuses on the initial phases of creating Aerial Ports of Debarkation and Sea Ports of Debarkation (APODs and

SPODs). None of these activities were relevant to research that the stakeholder was interested in, so they were considered to be out of scope.

Phase III: Follow-on Operations was also considered to be out of scope. These functions involve the long term support of the MEB ashore and the process of turning the occupation over to traditional ground forces that arrive by conventional means after the amphibious assault and initial engagements are completed. These activities were also considered to be out of scope.

Therefore, this study focused narrowly on Phase II: Gain Entry, and specifically on the vignette "Seizure of a lodgment and the rapid introduction of forces" (Wargaming Division. 2012, 8). This vignette provides functions that are useful for the analysis of interest to the stakeholder. They focus on forcible entry into a non-allied nation and operation in an A2/AD environment.

(2) EW12 Functional Architecture. The upper level functional architecture created from EW12 is shown in Figure 9. Although only a few of the decomposed functions were used for the research, it was necessary to create the entire functional architecture in order to accurately represent the entire problem. The function "F2-Perform Assault," in Figure 10, was further decomposed in order to obtain the more specific functions needed to Perform Assault.

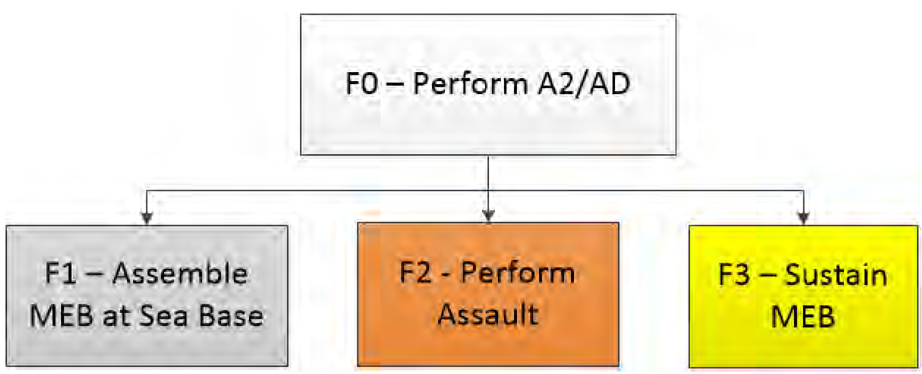

Figure 9. The upper level functional architecture for EW12 shows the three primary functions of F1-Assemble the Seabase, F2-Perform Assault, and F3-Sustain the MEB.

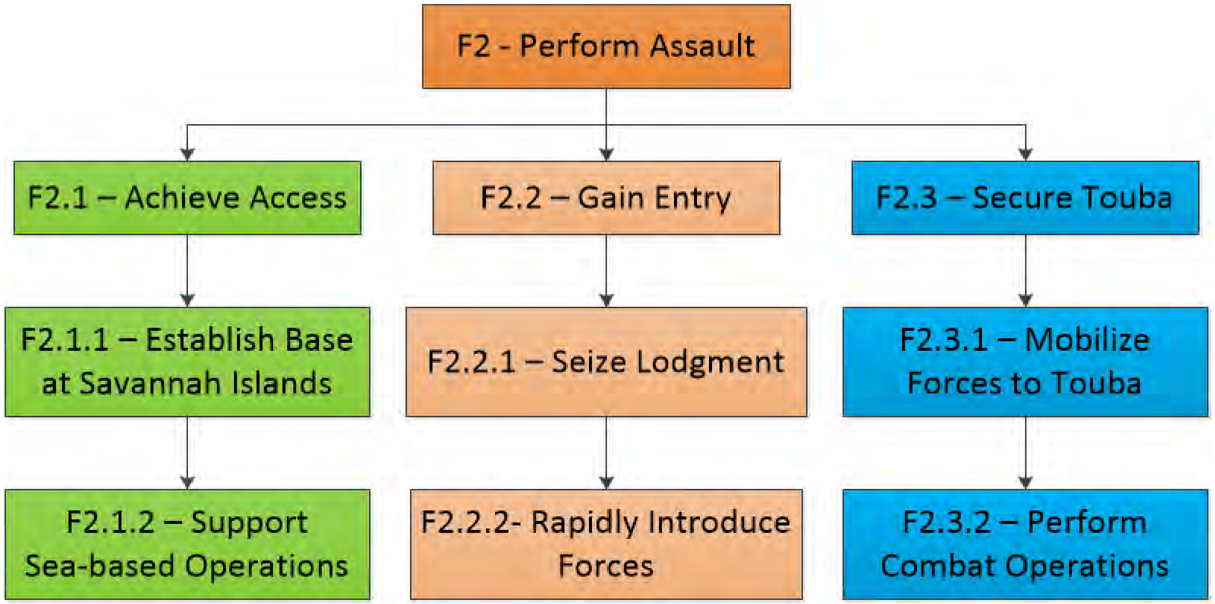

Figure 10. Function F2-Perform Assault is decomposed to obtain the lower level specific functions. From this decomposition, the sub-function of F2.2-Gain Entry was chosen for analysis.

The decomposition of F2-Perform Assault and F2.2-Gain Entry generated the following sub-functions:

- F2.2.1-Sieze Lodgment
- F2.2.2-Rapidly Introduce Forces

(3) Decomposition of the Sub-Functions. The two sub functions of F2.2.1-Seize Lodgment and F2.2.2-Rapidly Introduce Forces were chosen for decomposition into sub-functions that could be used to create the specific functions that the group could translate into capabilities and model. This was the lowest level of the Functional Architecture that was derived from the EW12 exercise. EW12 was essential in providing a legitimate source for determining the mission to be executed.

In order to perform the next two levels of functional decomposition, guidance on Amphibious Doctrine was researched to provide the necessary details. Doctrine was utilized to bridge the functional decomposition from the higher more abstract levels as discussed in EW12, to the lower more specific levels that were necessary in order to create a realistic model for analysis.

(4) Decomposition of F2.2.2 Rapidly Introduce Forces. F2.2.2.1 – Conduct surface-borne ship-to-shore Landing:

- F2.2.2.2 – Conduct Aircraft-to-Shore Landing
- F2.2.2.3 – Conduct Landing Force Support Party (LFSP) Logistic Support

The Cohort researched and used the Marine Corps Warfighting Publications (MCWP), specifically MCWP 3-31.5 ship-to-shore movement, NTTP 3–02.1M, May 2007 to decompose the upper level functions of the MEB in the EW12. The functional architecture begins to take a distinctive shape of three primary functions as seen in Figure 11.

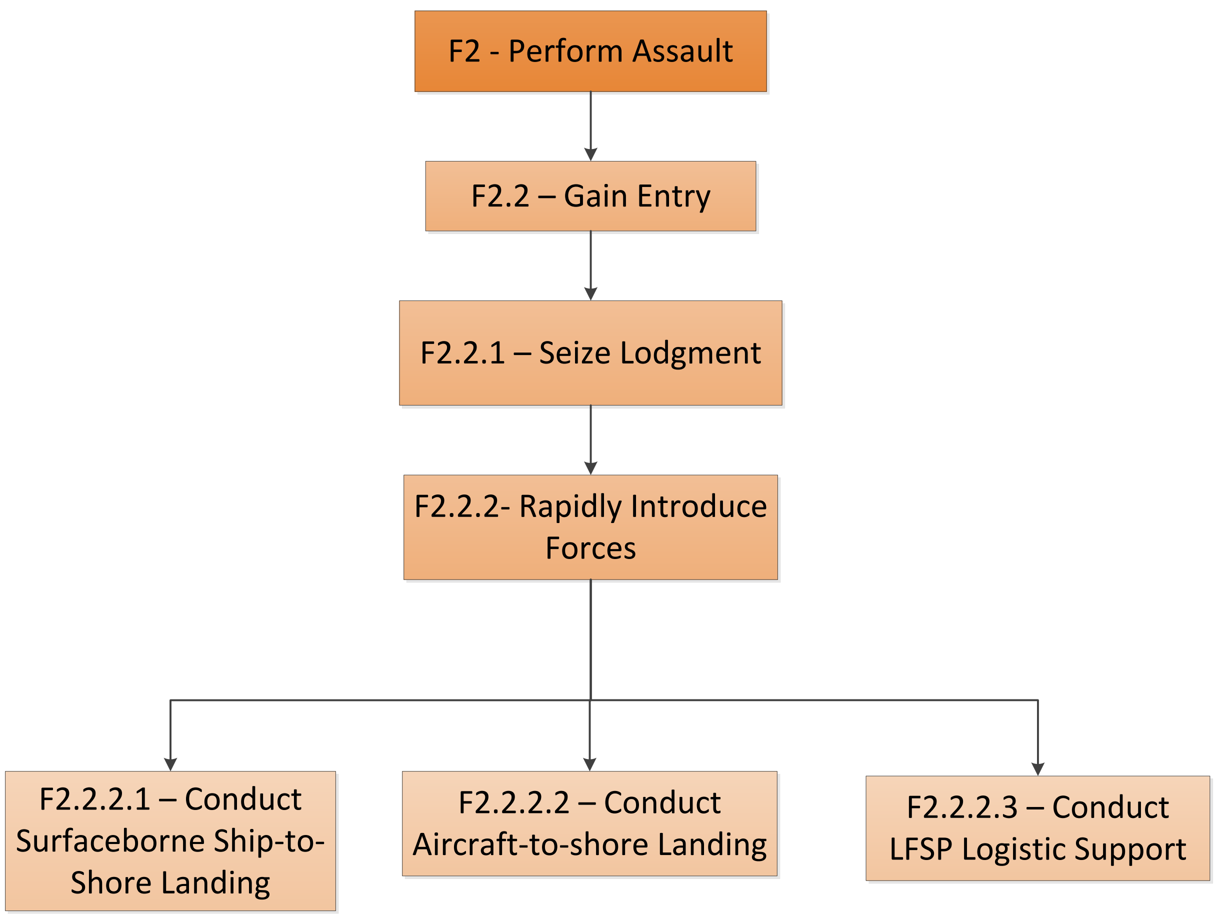

Figure 11. F2.2.2-Rapidly Introduce Forces is decomposed into sub-functions, which consist of conducting surface landings, aircraft landings, and LFSP logistical support.

(5) Rapidly introduce forces. The primary functions are divided into (1) surface-borne ship-to-shore landing, i.e., landing crafts that are deployed from seabase vessels, (2) Aircraft-to-shore landing, i.e., aircraft launched from seabase vessels , and (3) LFSP logistic support, i.e., provide command and control and logistics support for the landing party from seabase vessels to shore. These three components are necessary to perform the overarching function F2 Perform Assault.

Surface-borne ship-to-shore landing has discrete categories of amphibious elements that must be split into their own categories of vessel type and methods of landing, shown in Figure 12. The amphibious elements are decomposed to lower level functions as follows (Office of the Chief of Naval Operations. 2007, 4–8, 9):

- F2.2.2.1.1.1 – Displacement Landing Craft (DLC)
- F2.2.2.1.1.2 – Landing Craft Air Cushion (LCAC)

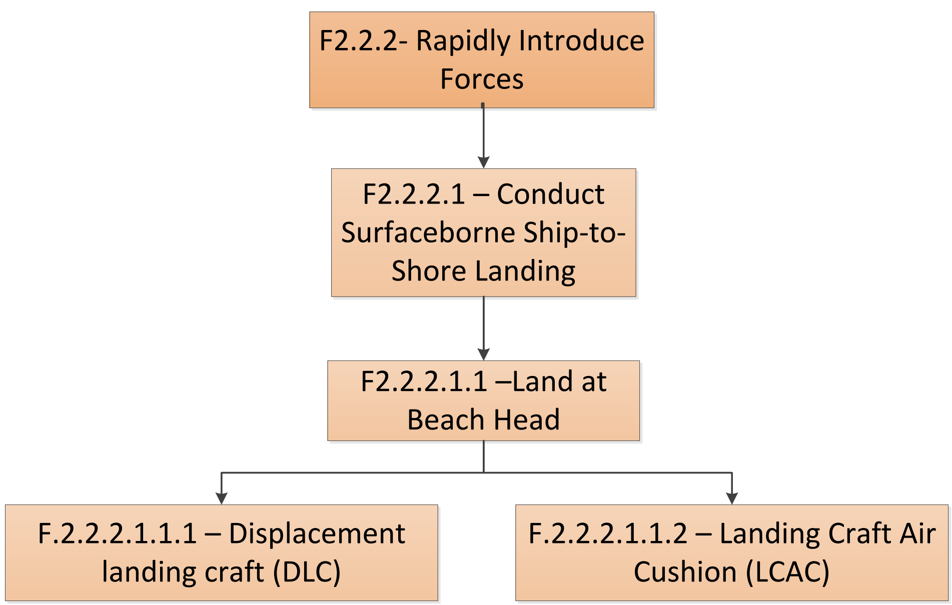

Figure 12. Surface-borne ship-to-shore landing is decomposed by two different surface-borne connector vehicles, DLC and LCACs.

These two sixth-level functions were decomposed further down to level seven. At the seventh level the functions uncover the measures of performance inputs that will flow back up to the measure of effectiveness as stated earlier. The Displacement Landing Craft (DLC) was decomposed into five lower functions that show

the operational execution of the DLC. The DLC first debarks and approaches the beach, once it beaches the offload begins. After offload is complete the DLC retracts and embarks to the seabase. The functional architecture for the DLC is shown in Figure 13.

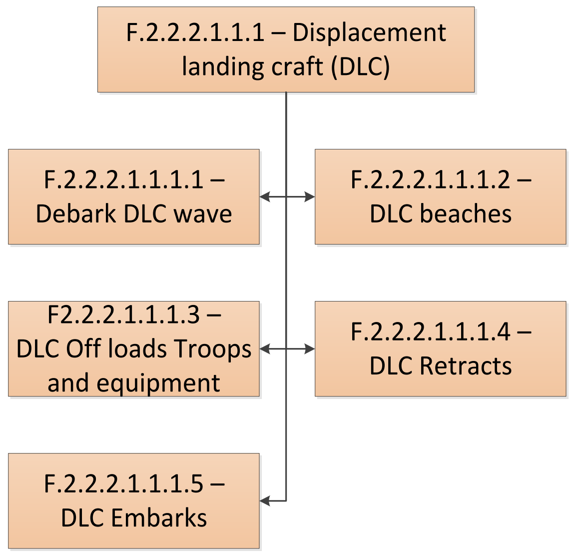

Figure 13. The function Displacement Landing Craft is decomposed into the following sub-functions: debark, beach, offload, retract, and embark.

At this level the attributes of the ship-to-shore movement of the DLC can be assessed. The five functions for the DLC can directly affect the two MOE's; throughput of connectors and reduction of fuel which are traceable through the MOP's; Utilization of Service bays at seabase, Average delay of connectors waiting to transport MEB, and Fuel consumed by connectors during conduct of amphibious assault. This level of the functional architecture can now be assessed by model based system engineering and eventually computer simulation of the ship-to-shore movements of the MEB.

The LCAC was also decomposed to the seventh level into five operational functions of the LCAC during ship-to-shore movement (Office of the Chief of Naval Operations. 2007, section 4). The LCAC first launches from the seabase and moves toward the beach passing the penetration point, then offload occurs. After offload the LCAC returns to Craft Holding Area (CHA) and then is recovered by an amphibious ship. The decomposition of the function LCAC is shown in Figure 14.

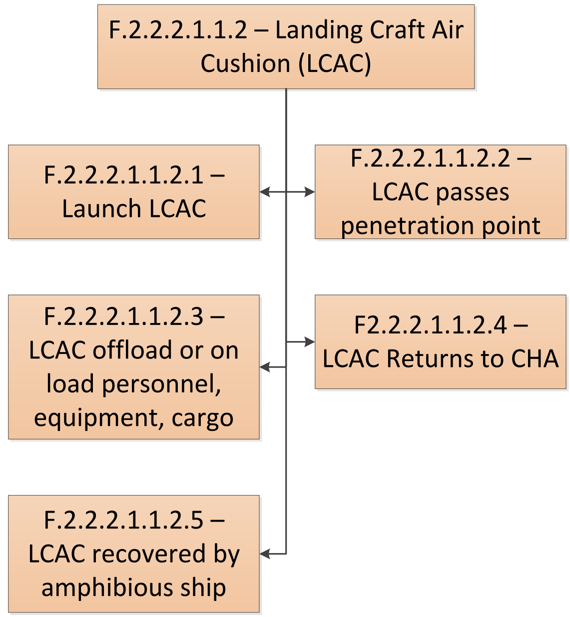

Figure 14. The function Landing Craft Air Cushion is decomposed into the following sub-functions: launch, pass penetration point, offload, return to CHA, and recover.

Like the DLC, the LCAC is now decomposed to a level that the attributes of the ship-to-shore movement of the LCAC can be assessed. The five functions for the LCAC can directly affect the two MOE's; throughput of connectors and reduction of fuel which are traceable through the MOP's; Utilization of Service bays at seabase, Average delay of connectors waiting to transport MEB, and Fuel consumed by connectors during conduct of amphibious assault.

The Aircraft-to-shore landing decompositions are more operational functions than surface-borne ship-to-shore landing decompositions. The Aircraft-to-shore takes on multiple roles during operations from the seabase to land maneuvers and different aircraft can take on the same roles within the functional architecture. For example a helicopter can transport troops, supplies and provide an offensive or defensive role in combat. The MV-22 can take on the same roles as a helicopter; therefore, the lower level functions were decomposed into an operational aspect instead of the operational hardware like surface-borne ship-to-shore decomposition and different

aircraft can be inserted as needed to execute the operation. The aircraft-to-shore landing was decomposed into four primary functions shown in Figure 15 (Office of the Chief of Naval Operations. 2007, 5–1-34).

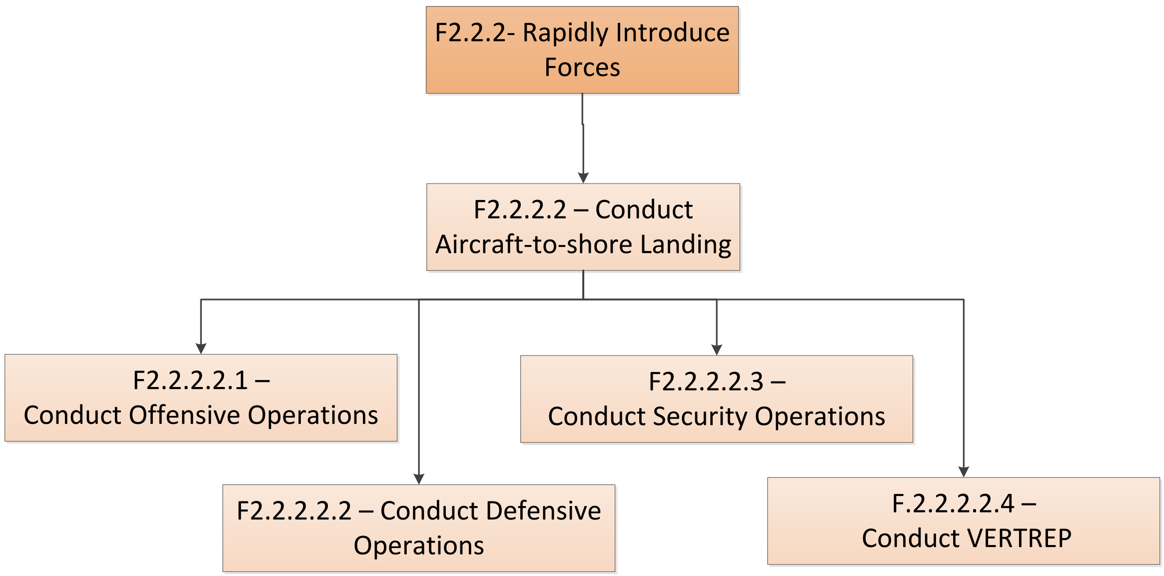

Figure 15. The function conduct aircraft-to-shore landing is decomposed into conducting offensive/defensive operations, security operations, and vertical replenishment (VERTREP).

Utilizing MCWP 3-31.5 ship-to-shore movement specifically Chapter 5 and Appendix H, the four functions derived from the aircraft-to-shore landing were easily decomposed to the sixth level. For Conduct Offensive operations, there were three lower level functions; seize key terrain, overcome obstacles, insert or extract personnel. These functions were left at this level as this project is not to develop tactical combat operations. For Conduct Defensive Operations, there were also three lower level functions; block enemy penetration or withdrawal, reinforce encircled forces, and insert and extract personnel like the offensive operations the defensive functions were left at this level as this project is not developing tactical combat operations for the warfighter. The lower level functional architecture is shown in Figure 16.

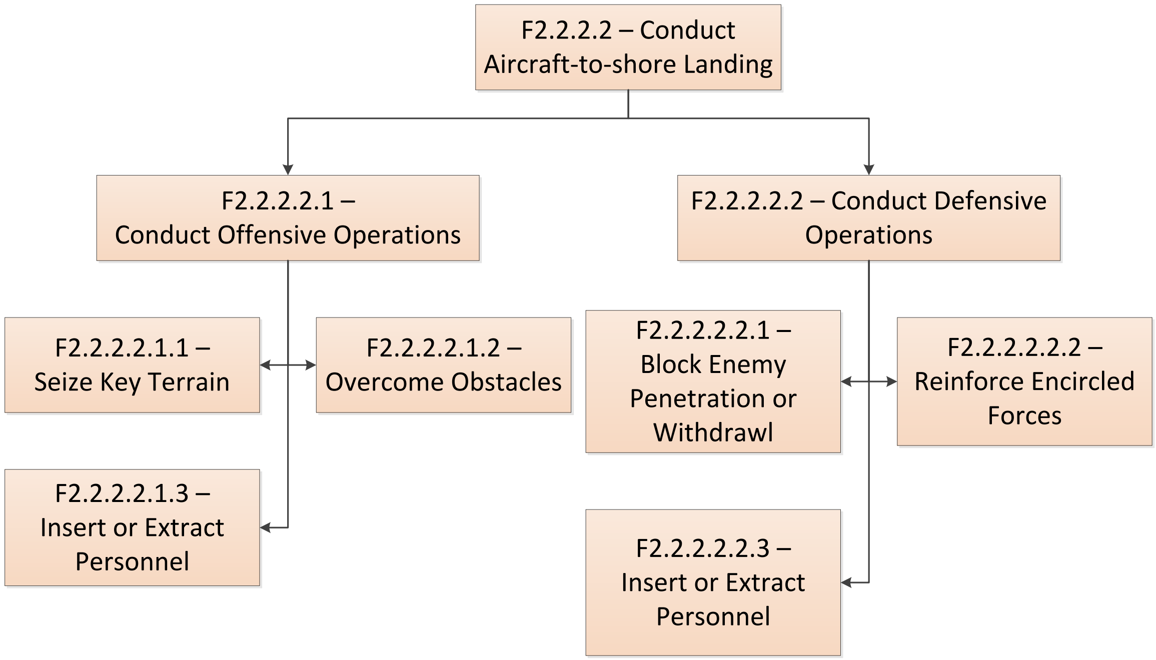

Figure 16. The decomposition of aircraft offensive and defensive operations

The final two functions under Aircraft-to-shore landing are conduct security operations and conduct VERTREP. Conduct security operations was decomposed into two lower level functions; Conduct counter attacks and reposition forces. Like the offensive and defensive operations the security operations were left at this level for the purpose of this project and there is no intent to develop tactical combat operations from this project. Conduct VERTREP was decomposed into three lower level functions Movement of medical supplies, Movement of spare parts, and Movement of ammunition, shown in Figure 17.

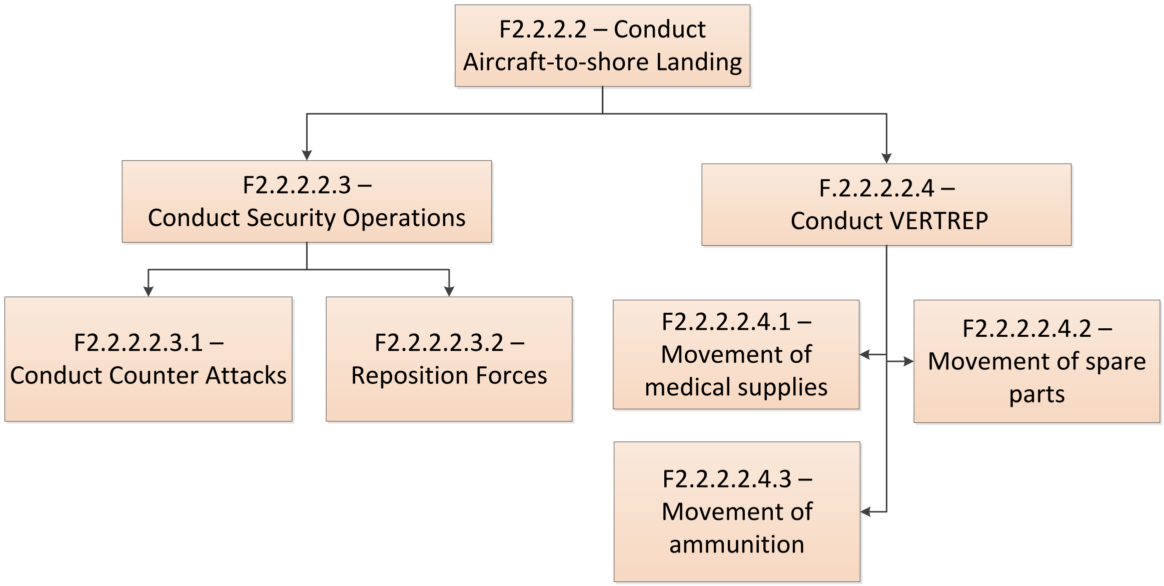

Figure 17. The decomposition of conduct security operations and VERTREP is shown.

The last function decomposed from Rapidly Introduce forces is Conduct Landing Force Support Party (LFSP) Logistic Support function (Figure 18). This function was decomposed from the overall aspect of the ship-to-shore movement of the MEB (Office of the Chief of Naval Operations, 2007, Appendix G). The LFSP was decomposed into five primary functions as follows:

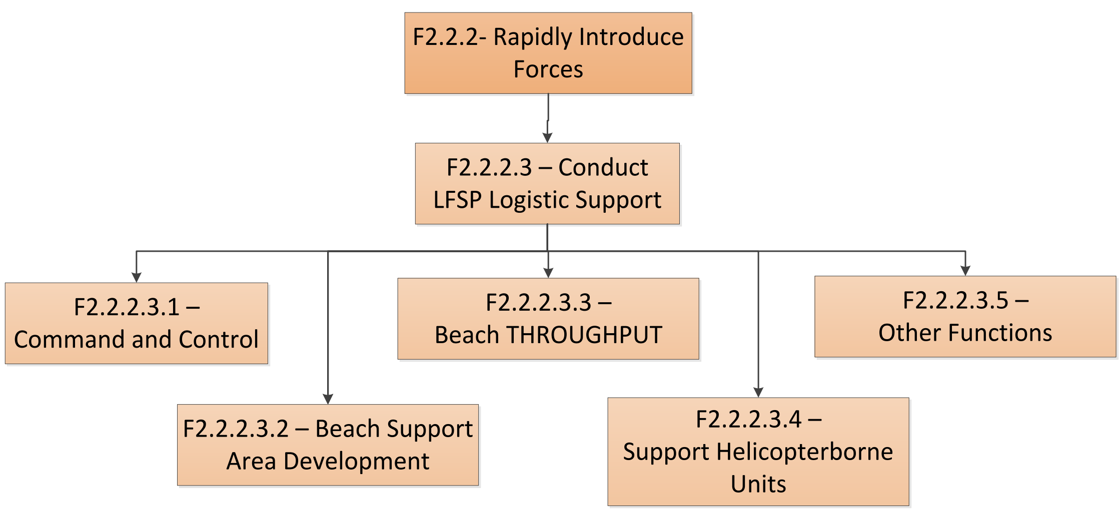

Figure 18. The decomposition of LFSP Logistic Support into command and control, beach support area development, beach throughput, helicopter-borne units, and other functions is shown.

The LFSP not only provides Command and Control (C2) for the MEB but it also "provides an organized and uniform flow of personnel, equipment, and supplies over and into beaches and Landing Zones (LZ)" (Office of the Chief of Naval Operations, 2007,G-1).

The decomposed functions for LFSP represent the necessary operations that must be provided during a beach landing much like the operation functions of the aircraft-to-shore landing function decomposition. These functions provide the organization the landing party needs once on land to effectively execute their mission. The LFSP allows the warfighters to execute their job and not have to provide their own logistical support.

Utilizing MCWP 3-31.5 ship-to-shore movement Appendix G, the five lower level functions of LFSP support were decomposed (Figure 19). Command and Control function was decomposed into five lower level functions; establish and operate information centers, control traffic to shore, maintain communications with Surface-borne and airborne commanders, lateral communications between beaches and Landing Zones (LZ), and maintain record of units, equipment, and supplies brought ashore. These functions are at their lowest level necessary for this project. The Beach support area development was decomposed into seven lower level functions; select landing locations, mark unloading sites, construct helicopter landing sites, establish supply dumps, mark and remove obstacles, construct and maintain beach lateral and exit roads, and provide local security. There is one very important function that the cohort will be evaluating with in the command and control architecture which is control of traffic to and from shore, one part of this project will look at how waves are deployed and if there is efficiencies that can be gained by changing deployment strategies.

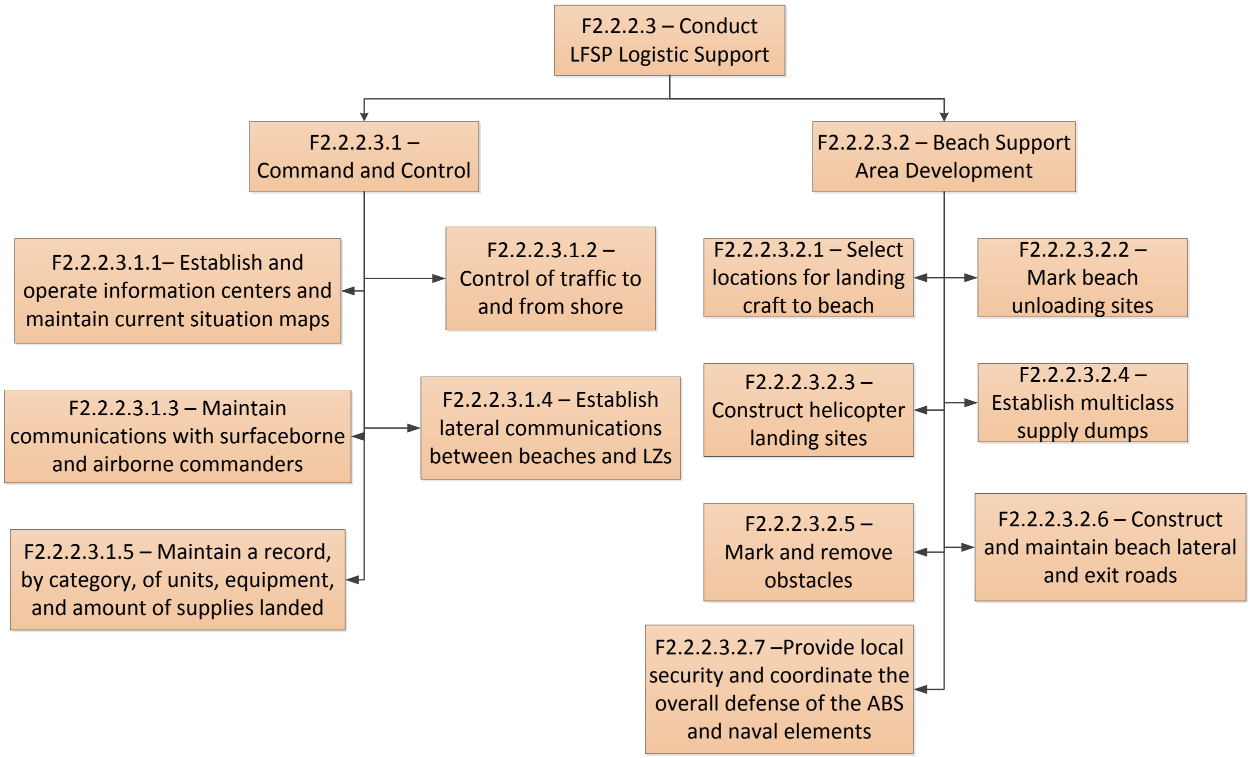

Figure 19. The decomposition of Command and Control and Beach Support Area Development into its sub-functions is shown.

The final three lower level functions of LSFP Logistic Support were decomposed to the sixth level. Beach THROUGHPUT was decomposed in to five lower level functions; assist in landing and moving across beaches, coordinate movement of amphibious vehicles and supplies, Operate ABLTS facilities provide emergency maintenance, and load aircraft with supplies for further inland delivery. Support Helicopter-borne Units was decomposed into one lower level function; provide landing support and HCEs to the helicopter units HST. The final function is Other Functions which was decomposed into four lower level functions; process requests from LF units ashore for supplies, establish and operate forward armed refueling points, establish and operate evacuation stations, and establish and operate enemy POW holding facilities. The functional architecture is represented in Figure 20. This level of functional architecture was evaluated and because of the scope described early for this project, these functions

although important to the MEB and the mission, it is beyond the scope of the project for energy footprint reduction other than the above mention F2.2.2.3.1.2 Control of traffic to and from shore.

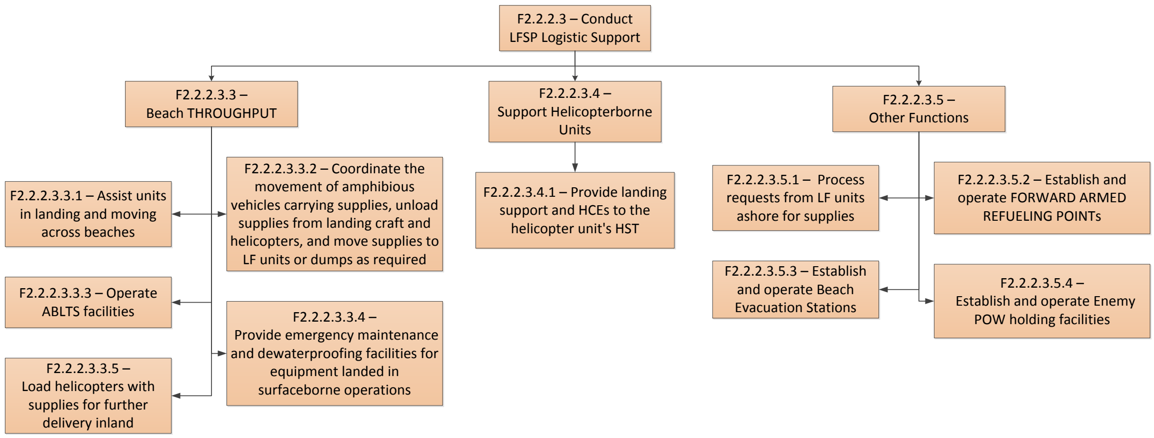

Figure 20. The decomposition of beach throughput, support helicopter-borne units, and other functions

2. Decomposing the Functional Architecture (CORE®)

Transforming the Functional Architecture that was created from EW12 and Marine Doctrine is the next step in the systems engineering process. Understanding how the functional architecture translates into a physical and operational entity was accomplished by using a model based systems engineering (MBSE) software, specifically CORE: "Model Based Systems Engineering (MBSE) quite literally means using a model as the central foundation of the process to gain insight into engineering the solution for a project" (Vitech Corporation, 2011, 1).

Utilizing the MBSE software CORE allowed the team to transform the functional architecture from a Microsoft Visio format to an integrate model that allows multiple diagrams and flow charts that allow the project team to see the functional architecture more clearly. With the end goal of making recommendations to reduce the energy footprint of the MEB it is the intent to be able to build a simulation model of how the ship-to-shore connectors interact with the seabase, the vehicles themselves, and landing at shore. Therefore, utilizing the MBSE software starts to transform the functional

architecture from a hierarchy diagram to more useful diagrams and flow charts like Functional Flow Block Diagrams (FFBD), Enhanced Functional Flow Block Diagrams (EFFBD), Integration Definition (IDEF0), and sequence diagrams tas a few examples.

The MBSE CORE software has enhanced the team's ability of understanding how the simulation model will work without painstakingly developing the simulation in the modeling graphical form. In other words, this was a simpler way for the team to understand, develop and agree to a basis for a simulation model.

The EFFBD was chosen because of its versatility of the diagram. See Figure 21 below and described here. The EFFBD takes the static functional architecture originally created and transforms it into a operational useful diagram showing not only the functional architecture (white boxes on the diagram), but also showing outputs of the functional architecture box (gray boxes on the diagram). Finally, the EFFBD also shows metrics that effect the functional architecture (green boxes on the diagram) from a modeling perspective, i.e., refueling times, time taken for movement, which calculates into fuel usage per time increment. For all of the EFFBDs we want to make it very clear that while we are not trying to mirror combat, we are trying to model combat by including interruptions in service and possible increases in wait time for transfer of goods and personnel. The distance may be the same but the time will be randomized. The key is the time. Once a piece of equipment is operating, it is using fuel.

a. CORE DLC Decomposed

Following the functional architecture from the F2-Perform Assault through F2.2 gain entry/F.2.2.1 seize lodgment/F2.2.2 rapidly introduce forces. From rapidly introduce forces F2.2.2.1.1 land at beachhead, the EFFBD starts with the Displacement landing craft.

Figure 21 shows how the EFFBD for the DLC (1 of 3) was created using CORE, the bottom of the diagram has the entire EFFBD showing while there is a enlarge portion on the top of the figure for better viewing of the diagram. This portion of the DLC EFFBD starts at the Seabase location with either an initially loaded DLC or a returning DLC from deployment. Once the DLC is loaded (time to load) and refueled

(time to refuel) then they move to the Debark wave function as a loaded DLC then the time in queue starts until it is released to the next function which is DLC beaches.

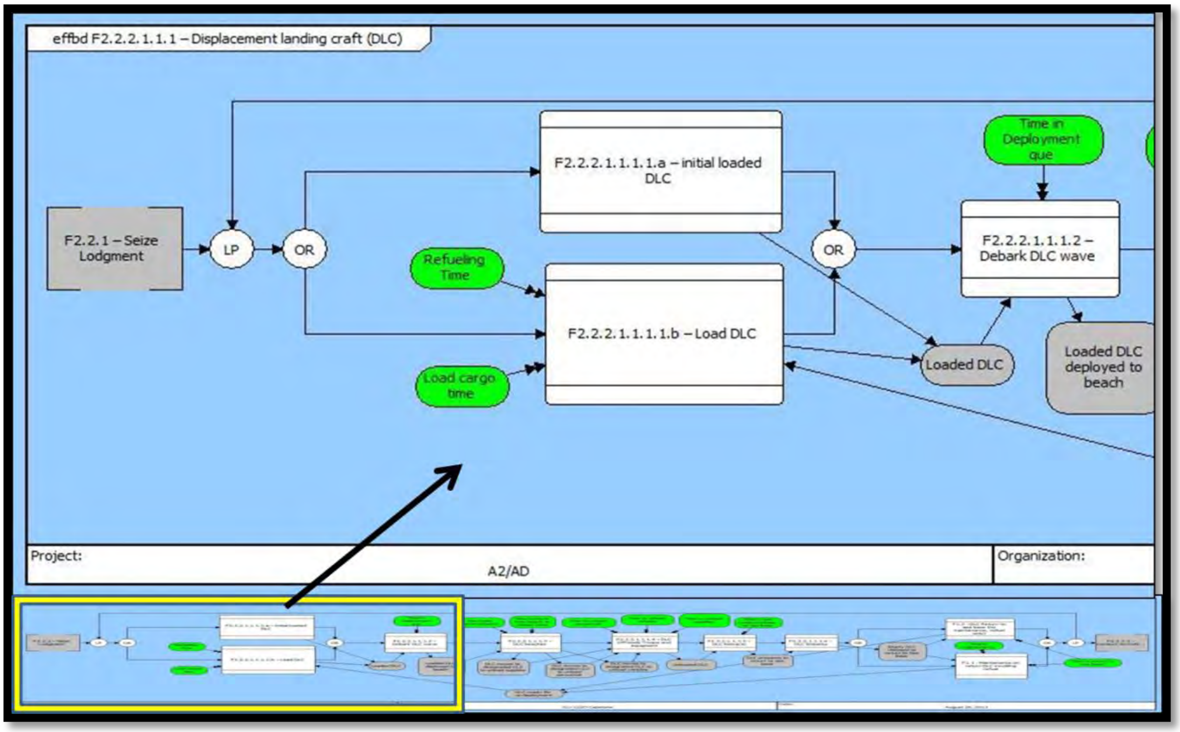

Figure 21. EFFBD for the DLC (1 of 3).

Figure 22 shows the EEFBD for DLC (2 of 3). This portion of the EFFBD shows the DLC beaches fully loaded with supplies/personnel/vehicles. The gray boxes are representing multiple scenario outputs of a loaded DLC and the green boxes are depicting different unloading times because of what is loaded on the DLC. Once offload has finished the DLC retracts and moves to debark the beach.

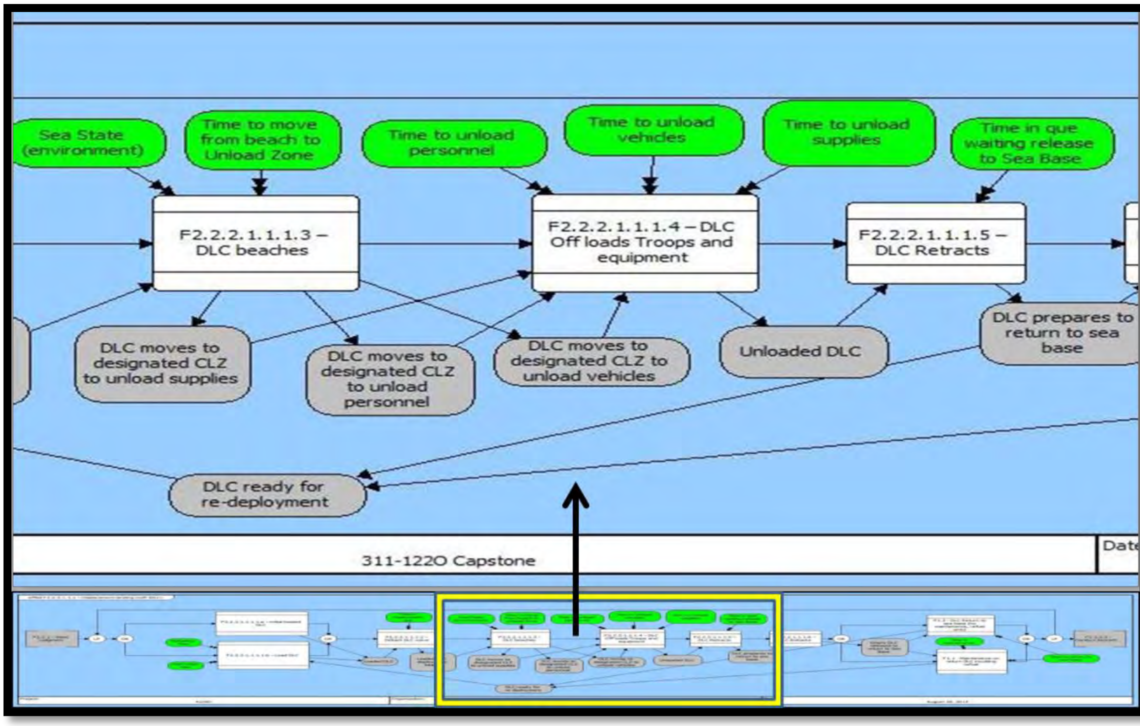

Figure 22. EFFBD for the DLC (2 of 3).

Figure 23 shows the DLC the completing the loop from seabase to shore and back to seabase. There are two scenarios for a returning DLC first no maintenance & refuel only; second maintenance is needed and refueling. There are different timing scenarios to account for; then the cycle repeats itself.

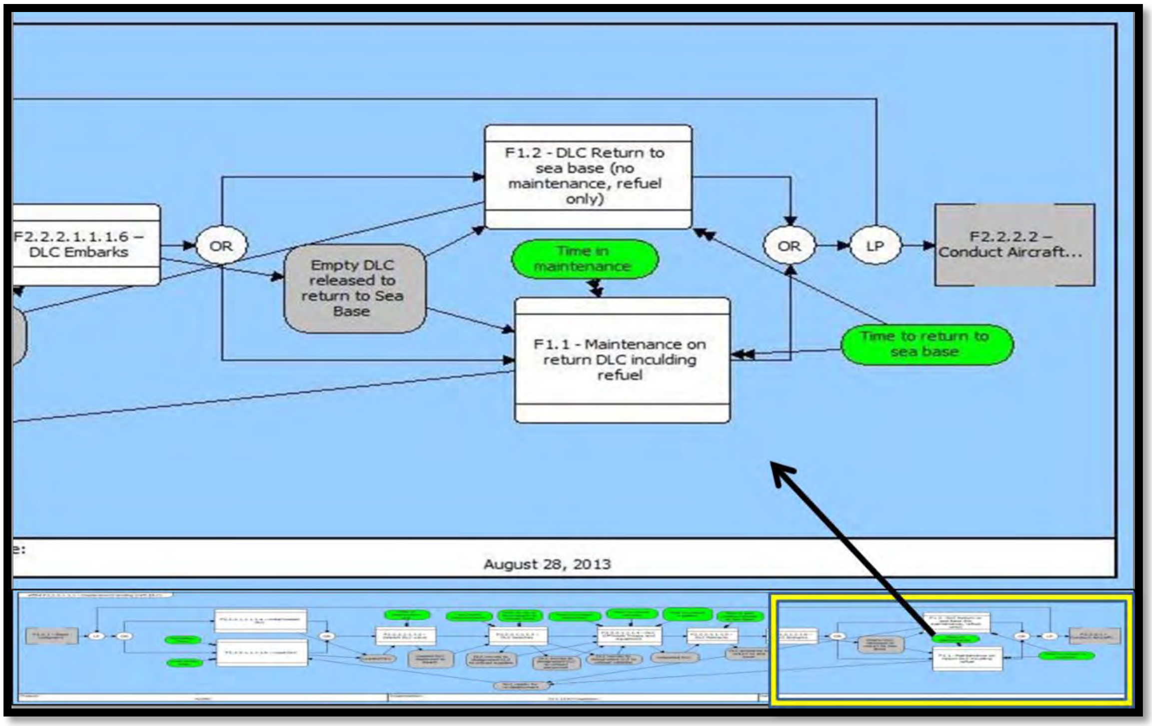

Figure 23. EFFBD for the DLC (3 of 3).

b. CORE LCAC Decomposed

Following the functional architecture from the F2- perform assault through F2.2 gain entry/F.2.2.1 seize lodgment/F2.2.2 rapidly introduce forces. From rapidly introduce forces F2.2.2.1.1 land at beachhead the second leg of the functional architecture is decomposed using CORE, which leads to LCAC.

Figure 24 shows the EFFBD for the LCAC (1 of 3), the LCACs start at the seabase either initially loaded or loading after returning from deployment. For the load function, loads times may vary depending on the items being loaded. Then the LCACs move from the load function to launching function of the LCAC. Here the LCAC might be held in the Craft Holding Zone until the wave is ready for deployment. Once launched, the LCAC heads to the beach craft landing zone (CLZ).

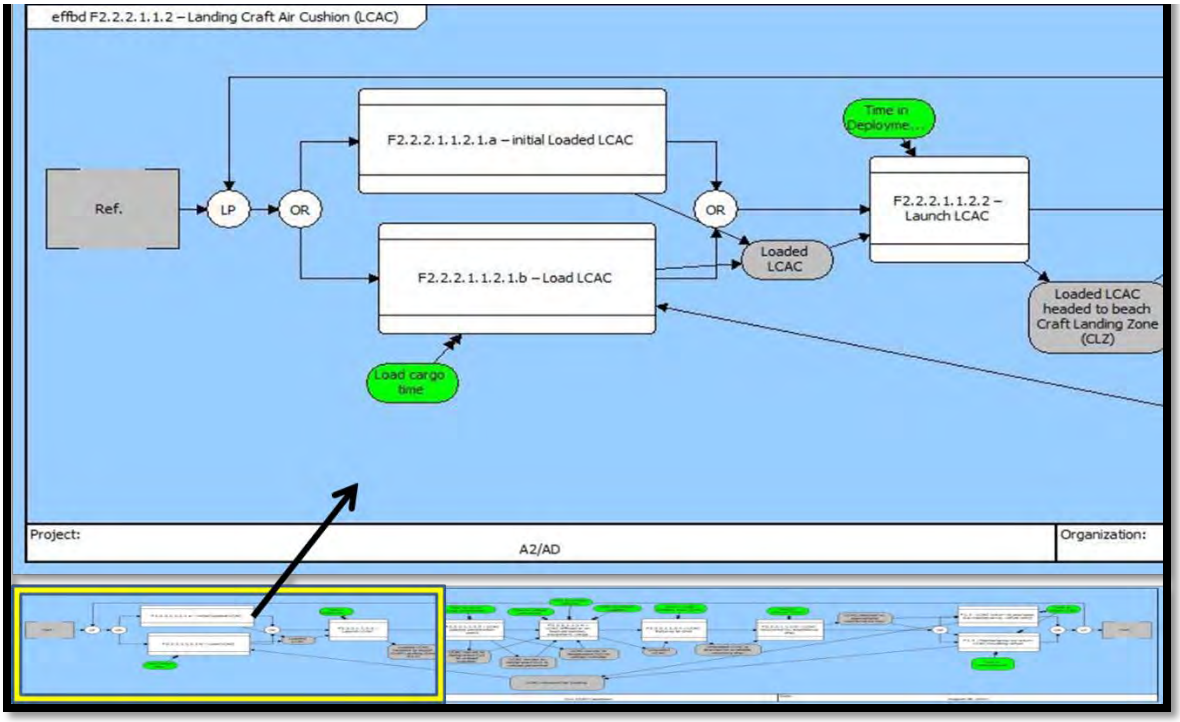

Figure 24. EFFBD for the LCAC (1 of 3).

In Figure 25 EFFBD for the LCAC (2 of 3), the LCAC passes the penetration point; here the LCAC can experience multiple environmental effects that effect the time to execute this function, items to consider are sea state, wind speed, and in general the weather as a whole. The fully loaded LCAC begins to offload with supplies/personnel/vehicles at the CLZ. There are multiple scenarios of a loaded LCAC represented on the figure which include supplies, personnel, and vehicles. For each of these scenarios, there are different unloading times because of what is loaded on the LCAC that can be considered. Once offload has finished, the LCAC leaves the beach and returns to the Craft Holding Area (CHA). The returning LCAC, depending on environmental conditions, can travel at a higher speed then on the inbound trip. Once at the CHA, the LCAC is placed in a queue to be directed to an available recovery ship.

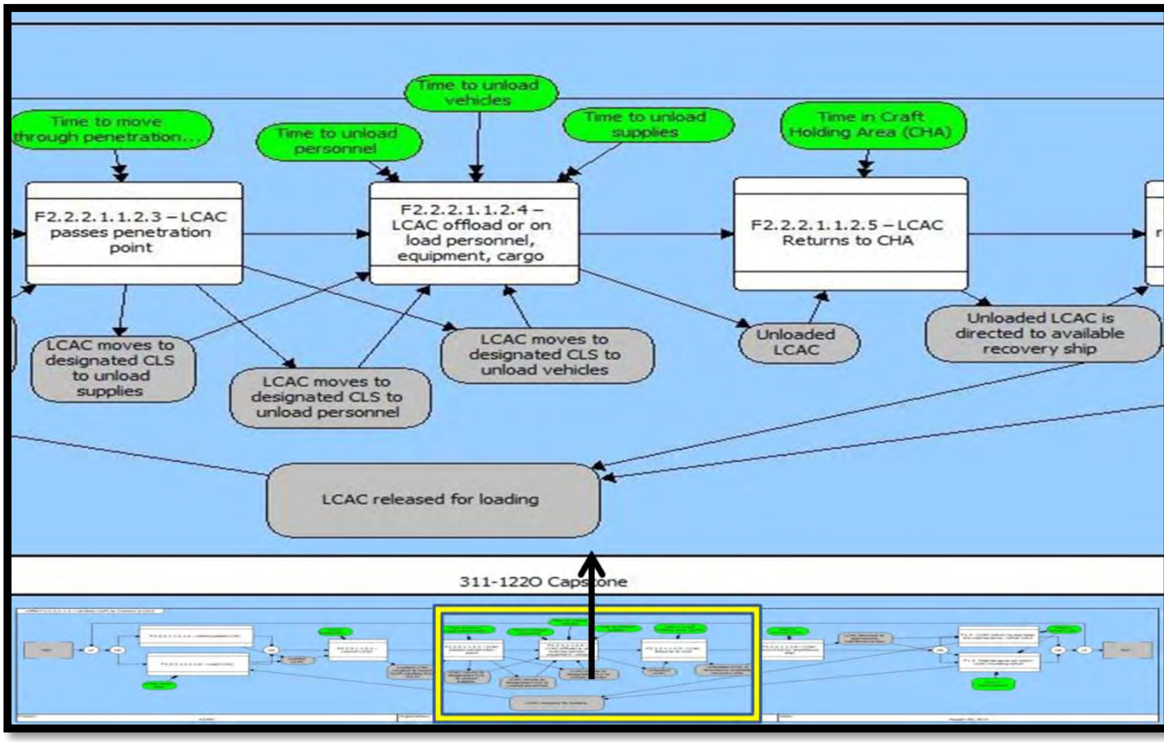

Figure 25. EFFBD for the LCAC (2 of 3).

Figure 26 EFFBD for the LCAC (3 of 3) shows the Final steps of the LCAC loop. The LCAC is directed from the CHA to the appropriate recovery amphibious ship. For this function, time in the queue here is important because the LCAC is continuously running which means fuel is being used while waiting. There are two options for the LCAC once is recovered. They are to have either maintenance performed and refueled or just refueled and then reloaded to be deployed to back into the cycle of the ship-to-shore connector.

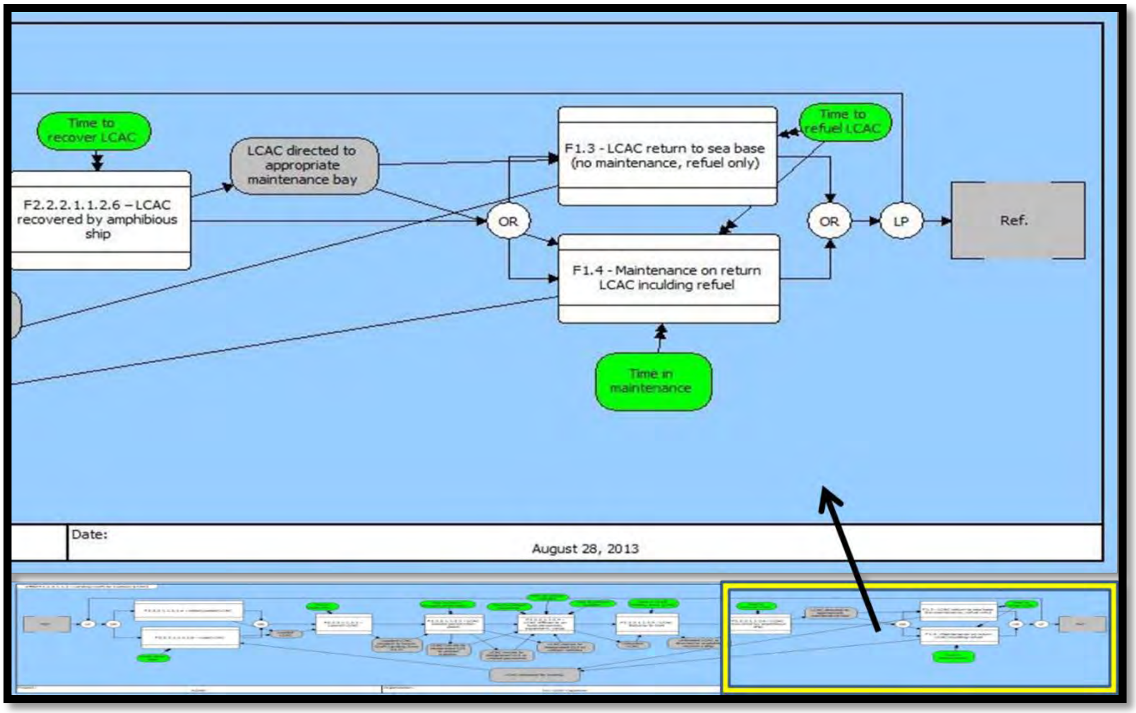

Figure 26. EFFBD for the LCAC (3 of 3).

c. CORE Aircraft-to-Shore

Figure 27 EFFBD of the Aircraft Offensive Operations (1 of 3), starts from F2.2.2.2 Conduct aircraft-to-shore landing. This EFFBD is not specific to one particular aircraft. The processes are being explored for the simulation models just as the processes for the DLC and LCAC were explored. Understanding combat operations are very dynamic, this EFFBD is not displayed as a combat plan but for modeling purposes, processes and expectations for the model. Figure 27 shows the aircraft starting at the seabase with either the initial load or the reloading from deployment and these have variable loading times. Then the aircraft exit the sea-base and move toward seize key terrain, fully loaded. Inputs here that would affect the time of execution would be the same as with the LCAC and DLC, which is environmental constraints at the time of deployment and with what the aircraft is loaded.

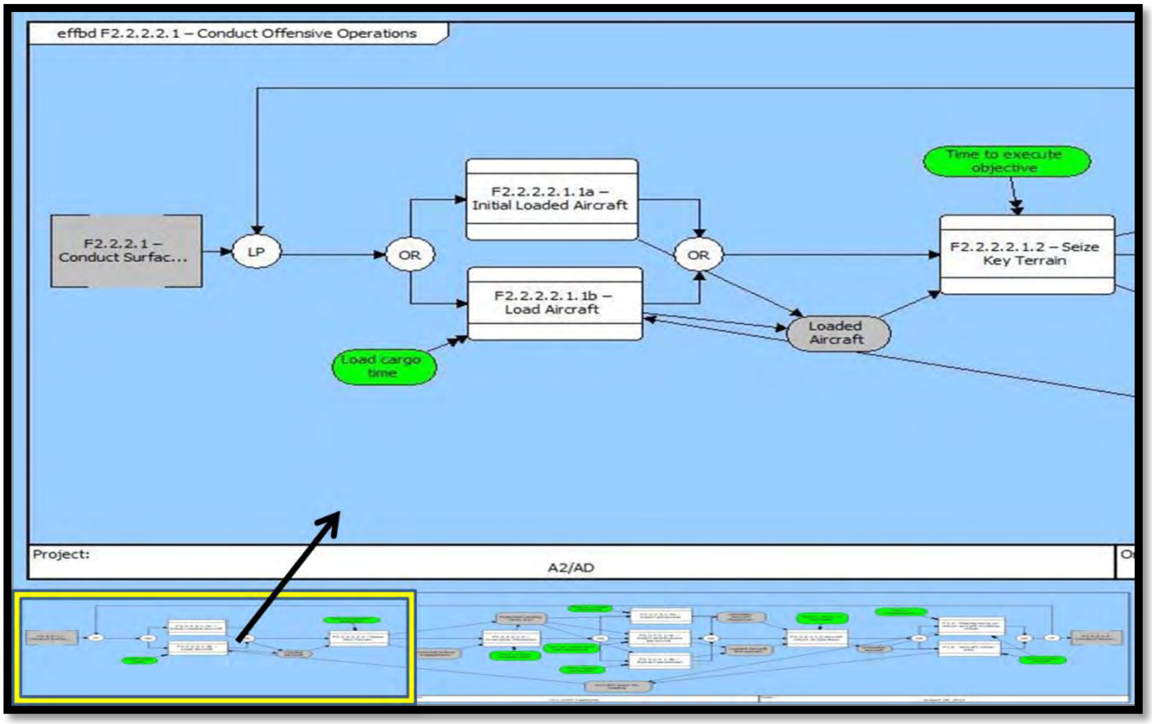

Figure 27. EFFBD for the Aircraft Offensive Operations (1 of 3).

After seizure of key terrain, the next function can be enemy engagement or attempting to find appropriate landing zones. The block is labeled "overcome obstacles" meaning finding landing zones to insert and or extract personnel. These functions would have variable timing inputs to execute the objectives of the functional blocks. The timing events include insert personnel and equipment, insert and extract personnel and equipment, and extract personnel, shown in Figure 28. Once these blocks are executed (personnel inserted / extract) the aircraft then proceeds back to seabase.

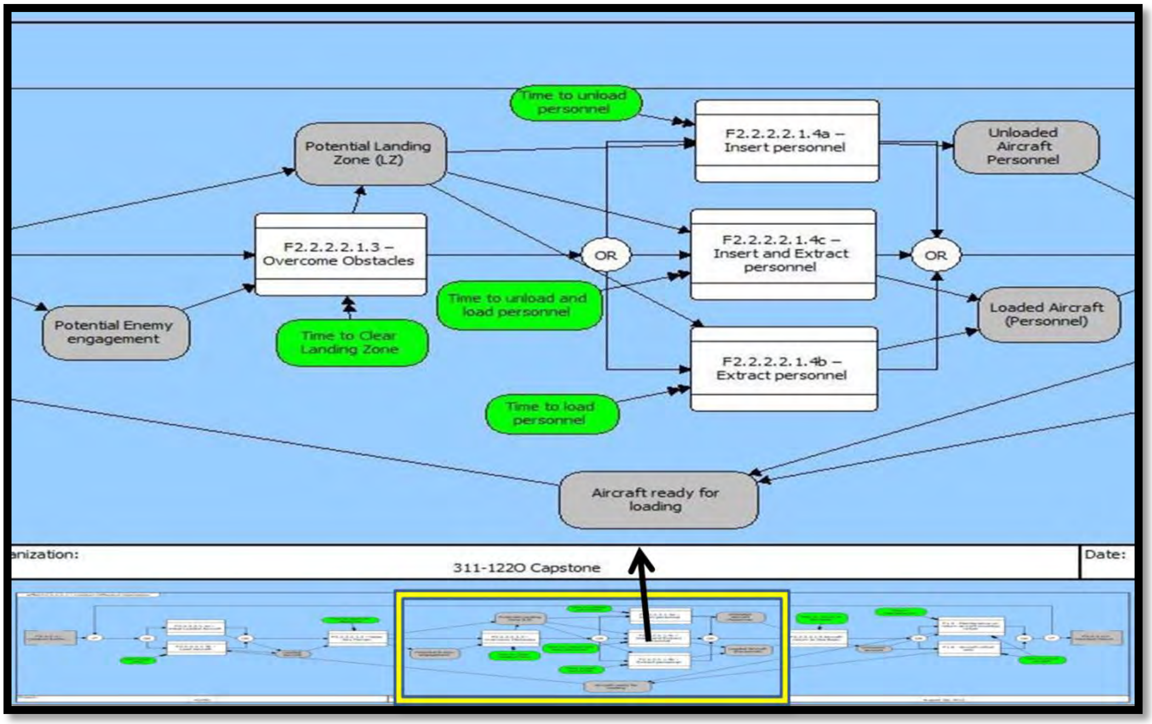

Figure 28. EFFBD for the Aircraft Offensive Operations (2 of 3).

Figure 29 shows the Aircraft Offensive Operations (3 of 3), during which time the aircraft return to seabase to unload personnel and reload for redeployment. There are multiple timing events that happen with the last functions which include travel time back to seabase, unloading and reloading times, and maintenance and refueling times.

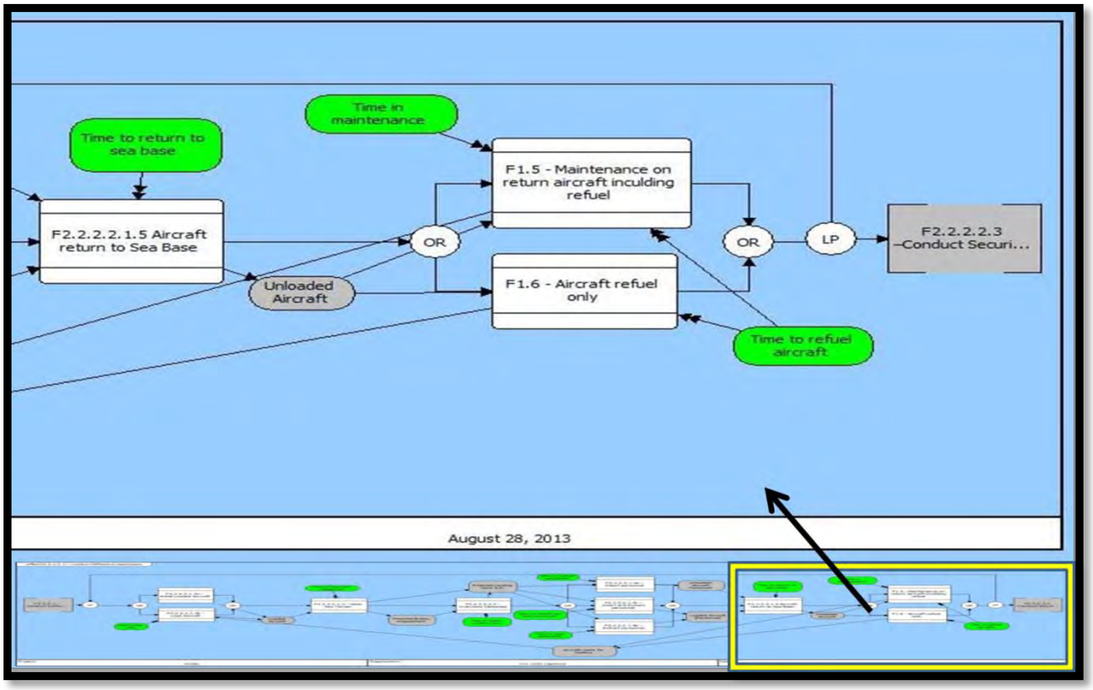

Figure 29. EFFBD for the Aircraft Offensive Operations (3 of 3).

The uses of CORE and MBSE have been valuable tools to start the simulation modeling processes. The CORE programming thoroughly integrates the EW12 scenario, and the static functional architecture, leading to fluid operational diagrams that depict inputs and outputs that are necessary to build an effective simulation Extendsim® model to evaluate the energy footprint reduction of the MEB. System Integration of information for MEB simulation, Figure 30 shows the traceability of the artifacts. These EFFBD(s) can be easily updated within the CORE software to represent final modeling simulation if changes of inputs or process have been changed during the building of the simulation.

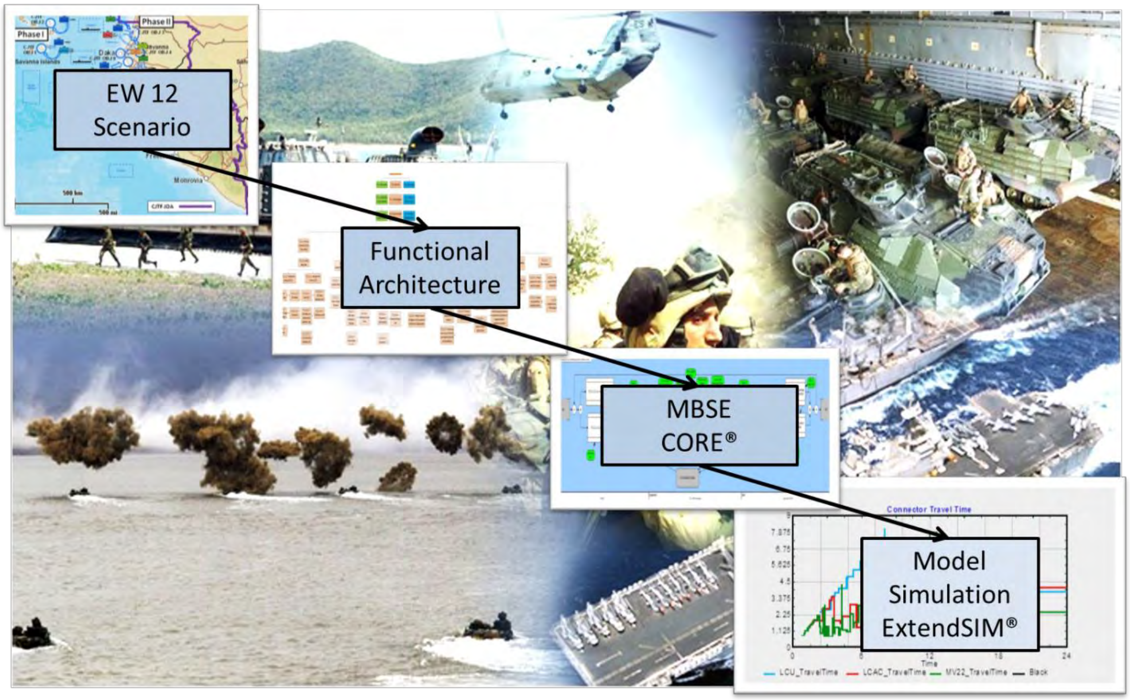

Figure 30. System Integration of information for MEB simulation.

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IV. MODELING, SIMULATION, AND ANALYSIS

A. MODELING METHODOLOGY

The capstone team examined and considered multiple types of process modeling and software packages. The team chose to use discrete event modeling in order to research tradeoffs to reduce fuel consumption, while still maintaining mission effectiveness. The overall modeling strategy was to build a simulation that represents the performance of a typical MEB conducting an Amphibious Assault during the EW12 scenario. To achieve this goal, the ExtendSim discrete event modeling software was utilized in order to build a stochastic model of the notional MEB architecture framework. In order to perform quality checks and discover design errors, the model was checked against an analytical model created using MS Excel. Once proper stochastic model performance was verified, a DOE approach was employed in order to determine the major influences that the variables exerted on the system architecture design.

1. Model Framework Representation

The initial goal of the simulation effort was to design and build a stochastic model that was functionally representative of the system architecture products described in Section III.C. The stochastic model was developed to represent the unique functions of the two main connector types; the surface connectors (LCU and LCAC) and the air connectors (MV-22, CH-53 and UH-1Y). In addition to the physical connectors, the model also included the queuing capacities and processes of the seabase loading sites, and the Beach Support Area (BSA) landing zones. These aspects were intended to examine whether seabase or BSA servicing capacities had an effect on overall system performance. These types of variables are referred to in the simulation as the "control variables."

Additional simulation variables were designed to represent the performance of the system in its representative environment. Factors such as sea state and SSD were selected to influence operational effects and limitations on the system's performance. These types of variables are referred to as the "noise variables."

In order for the stochastic model to accurately reflect the system functional architecture, as performed by its allocated connector components, a simulation review was conducted to validate the simulation processes and functional flow, against the system functions.

A simulation process flowchart is provided in Figure 31 to illustrate the process flows and decision structure of the simulation. The following section provides a narrative description of the flowchart processes and rationale for the simulation activity designs.

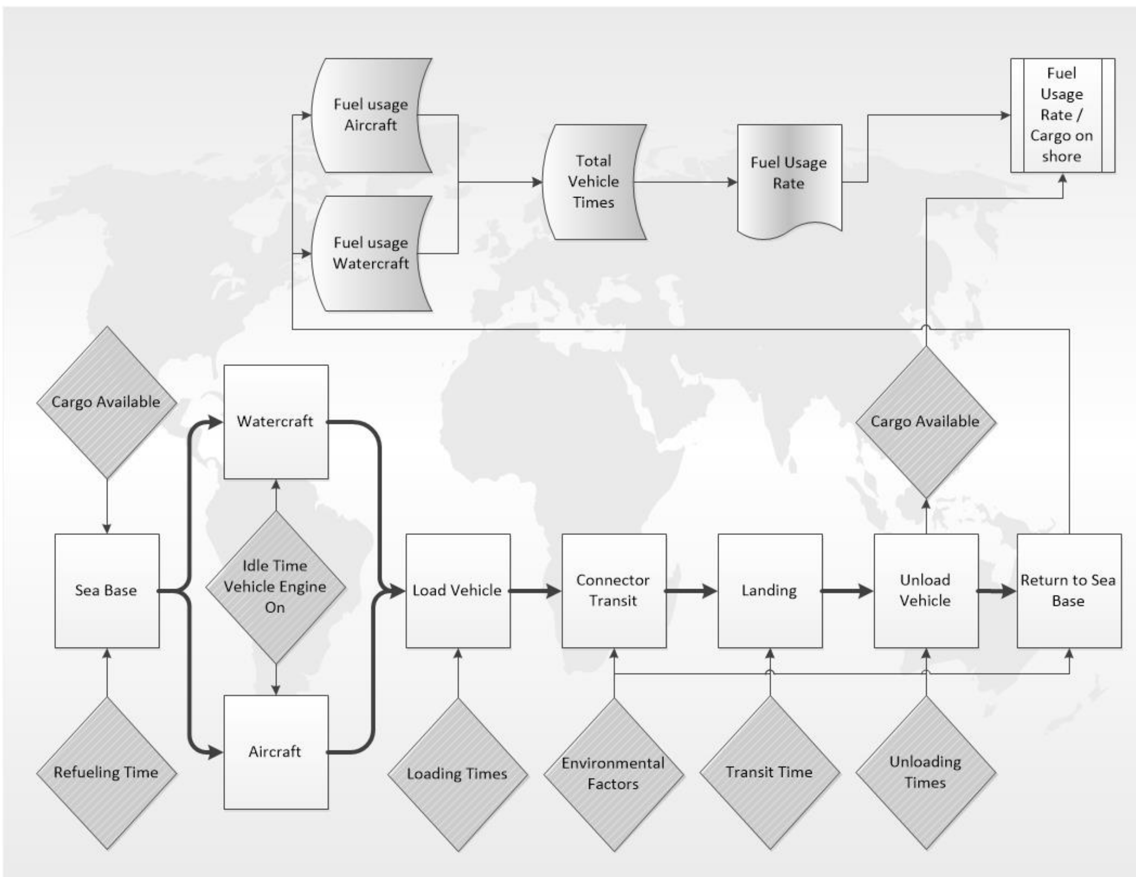


Figure 31. Simulation process flowchart.

2. Simulation Process Flow Description

During the simulation sequencing, the tempo of the events is set by two distinct phases; the “Assault” phase and the “Sustainment” phase. The “Assault” phase simulates

the operational activities of the connector system transporting the combat capable MEB force ashore. This phase is further decomposed into five (5) discrete waves, with the assault force converted into equivalent weight for the purposes of the simulation. A description of the operational composition of each MEB wave is provided in Table 5.

Table 5. Notional MEB amphibious assault waves used for the modeling of MEB amphibious operations.

WAVE	Description		Weight (Tons)	Quantity
1	AAVP-7	Amphibibious Assault Vehicle (with Applique Armor) + 18 troops	27.6	48
	LAV-25	Light Armored Vehicle 25-mm Gun (note 3)	12	25
	LAV-MEWESS	Light Armored Vehicle EW Variant	14.9	2
2	M1A1	Main battle tank	70	14
	M88A1	Tank Retriever	53.9	2
	M998	High Mobility, Multimission Wheeled Vehicle (HMMWV) (cargo/troops)	3.9	41
	M1045	HMMWV (weapons)	3.2	23
	M1043	HMMWV (Ammunition)	3.2	15
3	M252	MORTAR, MEDIUM, EXTENDED RANGE, 81MM, M252	0.05	24
	M224	MORTAR, MEDIUM, EXTENDED RANGE, 60MM	0.06	27
	M220E4	GUIDED MISSILE SYSTEM, TOW 2 WEAPON SYSTEM,	0.3	24
	M98A1	JAVELIN WEAPONS SYSTEM, COMMAND LAUNCH UNIT (CLU)	0.03	24
	M2	M2 .50 Caliber [12.7mm] Machine Gun	0.07	18
	MK19	Automatic Grenade Launcher, 40mm, Mk 19	0.07	18
	M240	MACHINE GUN 7.62MM,	0.02	54
	M249	Light Machine Gun, 5.56mm, M249	0.008	243
4	M198	155-mm Howltzer	7.9	24
	AVLB	Bridge	18.6	1
	D7G	Medium Tractor (bulldozer)	26.9	5
	M817	5-Ton Dump Truck	11.1	8
	M923	5-Ton Dump Truck (M198 Prime mover) + 19 man gun crew	15.9	8
	M923	5-Ton Cargo Truck (cargo)	15.9	15
	M931	5-Ton Semi-Tractor	10.2	15
	M936	5-Ton Wrecker Truck	18.3	5
	Mk48/Mk14	Logistic Vehicle System (LVS) (Note 4)	32.7	15
	Mk48/Mk16	LVS, 5th Wheel	20.8	9
	MC-4000	Rough Terrain Forklift	4.1	27
	DROT 2500	30-Ton Rough Terrain Crane	36.1	1
5	MC-6000	Rough Terrain Forklift	9.8	18
	72-31M	Rough Terrain Forklift	12.1	13
	LWPS	Lightweight Water Purification System (LWPS)	1.6	9
	07500C	Load bank 100kw gen NSN 6150-01-557-1304	0.5	44
	AAFS	FUEL SYSTEM, AMPHBIOUS ASSAULT	70	2
	LRT 110	CRANE, WHEEL MOUNTED, LIGHT,7.5 TON, NSN 6810-01-516-9718	11.4	5
	M120	ROAD GRADER	15.5	3

This notional MEB design was created based on research conducted by the team on similar compositions of MAGTFs from USMC doctrine documents and other USMC literature. The initial list of vehicles and equipment was obtained from the MEF Planner's

Reference Manual (MAGTF Staff Training Program, 1999, 2–3 through 2–8 and 4–82). The tables from this pamphlet were sized proportionately for a MEF, which was significantly larger than the MEB that was to be modeled. These quantities were reduced using rational assumptions based on the need for capability with respect to the missions anticipated from the EW12 scenario. When a rational assumption could not be made on the quantity of a vehicle or piece of equipment that was needed, a simple scaling factor was applied to the MEF quantity in order to reduce the number modeled. This assumption does not affect the modeling outputs because they are all obtained using weights as inputs. Weight is treated the same regardless of the platform that is represented by it, the modeling outputs are still valid, even if the vehicle and equipment make-up is not an exact representation of a current MEB.

Each wave was then converted into a common "weight" value, which is then "picked up" by a connector and transported to shore. In order to account for inherent inaccuracies of this conversion process, an inefficiency factor was added to each connector to account for the fact that not every platform will be 100% fully loaded, nor can an individual vehicle or component be "split up" between multiple connectors. On average, an efficiency factor of 90% was applied to each connector to account for this process.

Once the connector had delivered its portion of the MEB force on shore, the time elapsed measurement was recorded for that individual wave, and then the connector performed the return transit back to the seabase. Upon completing the round-trip, the fuel consumed for that wave was calculated based on the total time multiplied by the connector's average fuel burn rate attribute. This calculated value was entered into a database table in order to cumulate the fuel used by all connectors during that simulation run.

At the completion of the Assault phase, the simulation progresses to a "Sustainment" phase, which spans the remainder of the 30 Day Amphibious Assault mission duration. During this time frame, the bulk of the MEB force, or "Iron Mountain," is transported to the shore location. Similar to the Assault Phase, the Iron Mountain is converted to an equivalent weight value and allocated to individual connectors during

each trip. A description of the Iron Mountain allocation is provided in Appendix B.. In addition to this payload, additional resources are added on a daily basis to account for the expected demand of consumable supplies required to sustain the MEB on shore. These supplies are estimated in the form of food, water and ammunition consumables and are likewise converted to a common weight value which is added to the resource pool.

B. DESIGN OF EXPERIMENTS DEVELOPMENT

Once the DOE variables and the Noise Variables were defined, the relationships between these variables and the output responses were explored to determine the effects of the input variables on the output responses. Table 6 lists the initial simulation variables tested.

Table 6. DOE simulation variables.

Variable Type	**Variable Name**	**Range**
Control	Qty LCUs	4 – 16
Control	Qty LCACs	4 – 16
Control	Qty MV-22’s	0 – 30
Control	Qty CH-53’s	0-30
Control	Qty UH1-Y	0-30
Control	# Sea base Connector Capacity (zones)	10 – 30
Control	# BSA Unload Capacity (zones)	10 – 30
Noise	Sea State	0 – 6
Noise	Distance of Sea Base from Shore (nmi)	3 – 20
Response	Time to complete assault phase	N/A
Response	Fuel consumed during 30 day mission	N/A

As described in IV.A.1, the control and noise input variables are directly traceable to the system's functional and physical architecture components. The response variables described in Table 6 are directly traceable to the MOE's stated in Section III.B.1.B. The first MOE, "Throughput of the Connector system – Capability of Connectors to transport MEB," is defined by the simulation output response "Assault Time." This response variable measures the time required for the connectors to complete the transport of the first 5 waves, which represents the main amphibious assault force. Once the 5 waves have been successfully completed, it is recognized that the MEB is "combat capable" on shore and this first metric is completed.

The second MOE, "Reduction of fuel consumed by MEB during the conduct of an amphibious assault," is defined by simulation output response "Fuel Used." This response variable measures the total fuel consumed by all connectors allocated during the entire 30-Day simulation run, including both the initial assault phase and the sustainment phase. This metric is calculated and recorded at the end of each simulation run.

1. Experimentation Design

The strategy for experimentation design is laid out in Figure 32. The scope of this study focuses on the "Discovery" and "Breakthrough" phases as depicted in Figure 32. Because of the high number of factors to be initially evaluated in the simulation, a One Factor At a Time (OFAT) approach was determined to be impractical due to the extensive amount of runs required (Four levels over nine factors would equate to 4^9 runs, or 262,144 runs).

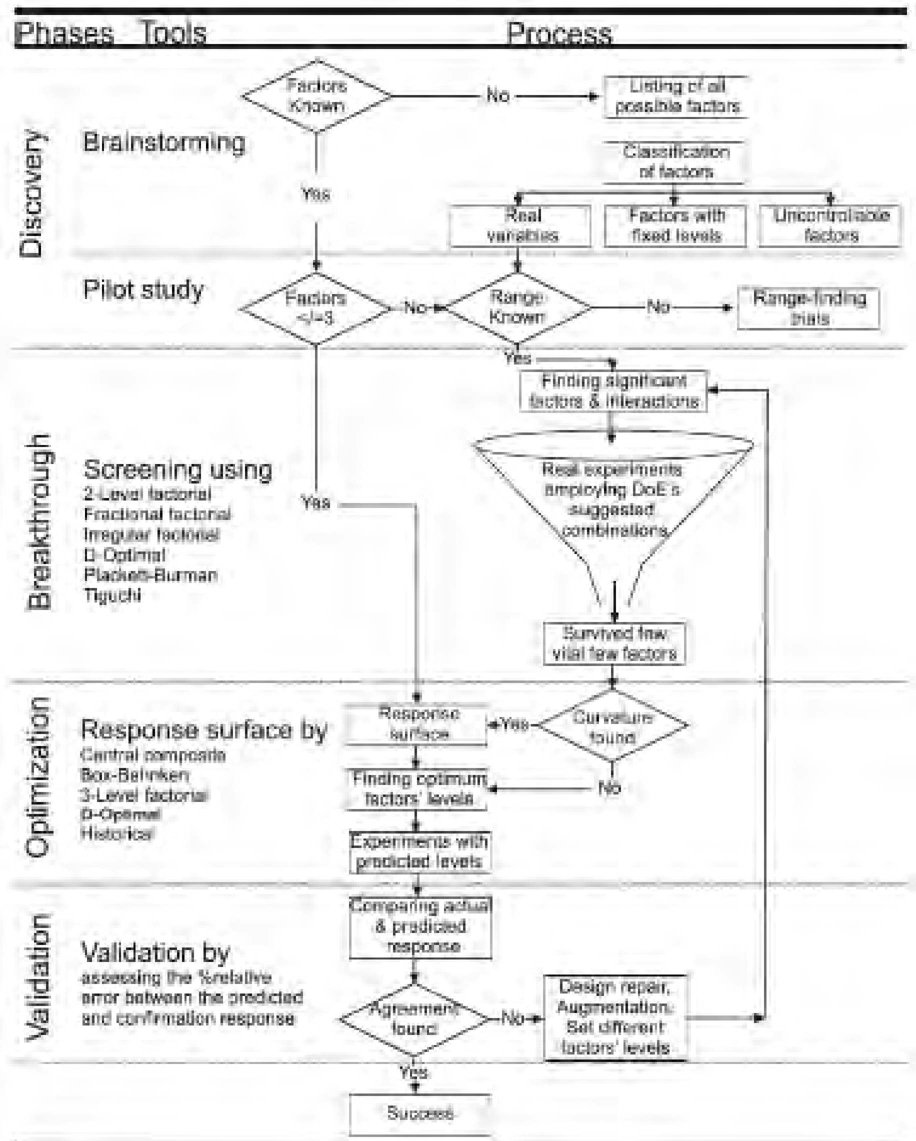


Figure 32. Experimentation design strategy (from Anderson, M.J.et al., 2007).

C. MODEL RESULTS

In order to establish factors of interest for evaluation, a preliminary 2-Level Factorial simulation experiment was developed utilizing the factors depicted in Table 6. The Full Factorial experimental design was performed through the ExtendSim discrete event model. The analysis results depicting the factor main effects for Assault Time and Fuel Usage are shown in Figure 33 and Figure 34 respectively.

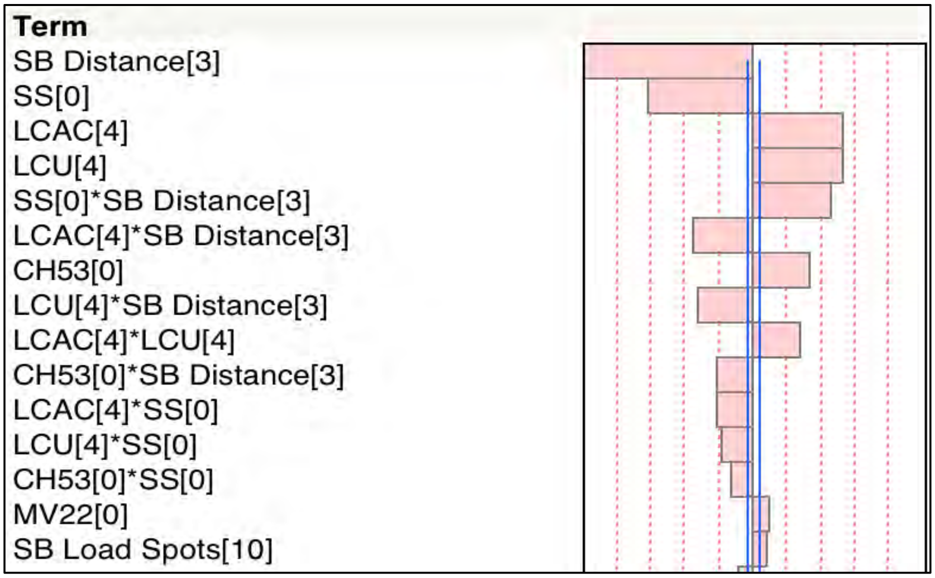


Figure 33. Sorted Effects Plot for Assault Time.

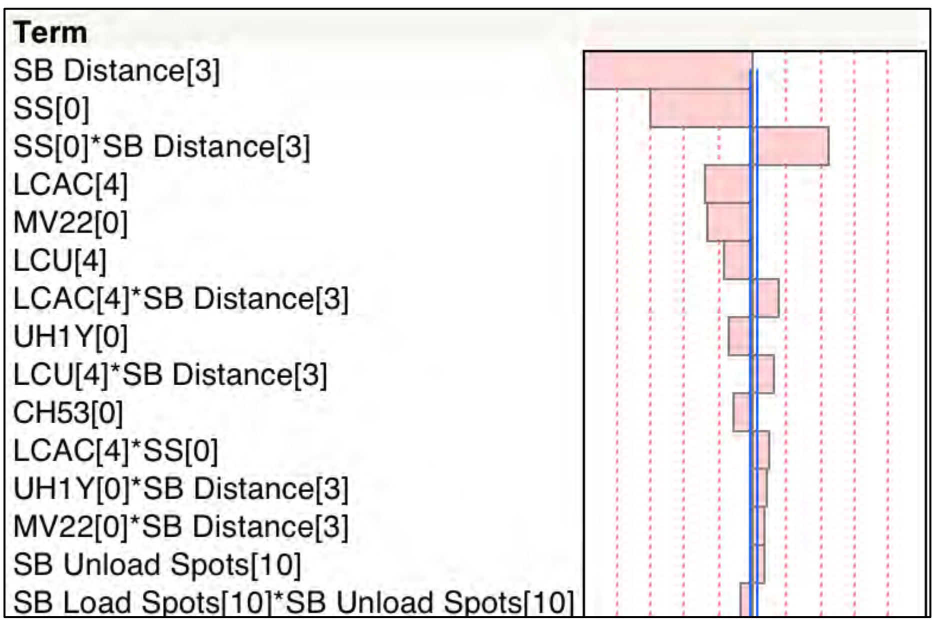


Figure 34. Sorted effects plot for fuel usage.

Some preliminary conclusions that were inferred from these initial results are as follows:

- The Seabase Distance and Sea State parameters have the most direct impact on both timely completion of the assault phase, as well as fuel economy

- The interaction of the Seabase Distance and Sea State factors is also a significant response. The fact that there is a positive coefficient implies that there is a beneficial component in this interaction

A Linear Regression model was generated given the input variables in order to observe the weighted contributions of the variables to the output responses. The positive contributions of the connectors are scored and ranked according to the calculated linear coefficients. A table of these coefficients is shown in Table 7.

Table 7. Linear regression model coefficients.

Connector	Assault Time Rank	Assault Time Coefficient	Fuel Used Rank	Fuel Used Coefficient
LCAC	1	2.6934422	1	-421702
LCU	2	2.6790299	3	-243035
MV-22	4	0.5128664	2	-38933
CH-53	3	1.656322	5	-170607
UH1-Y	5	0.0194285	4	-213635

A graphical version of these coefficients is shown in Figure 35 and Figure 36. These figures show the proportional weights that each input variable has on the output response. As can be seen from these results, the Seabase Distance and Sea State factors possess the largest impact on both Assault Time and Fuel Usage metrics.

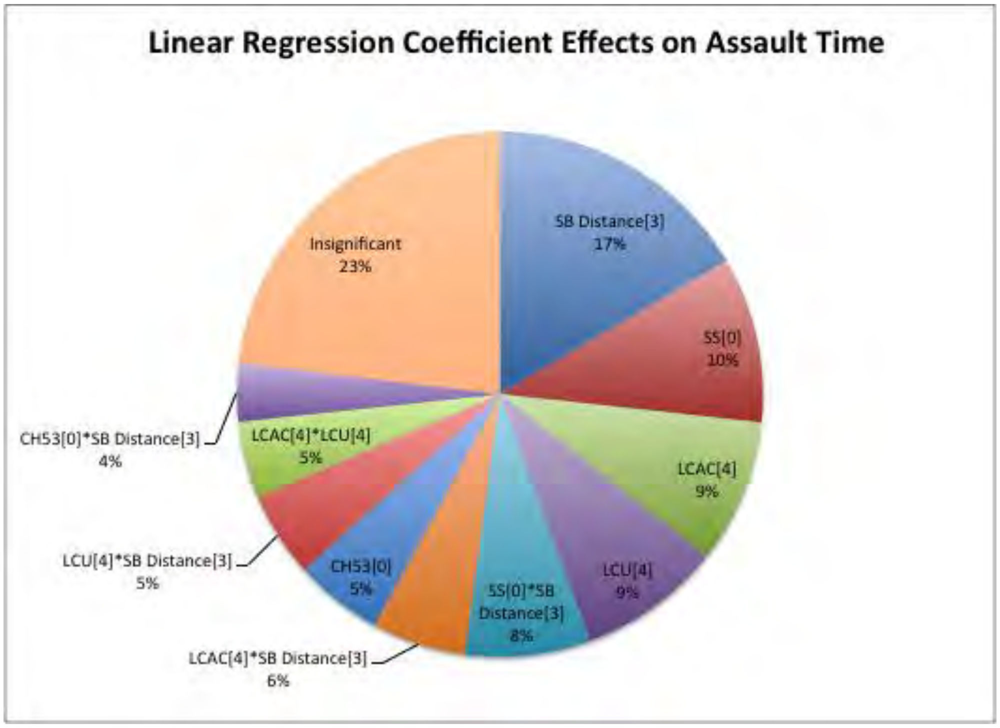


Figure 35. Coefficient proportions that affect assault time.

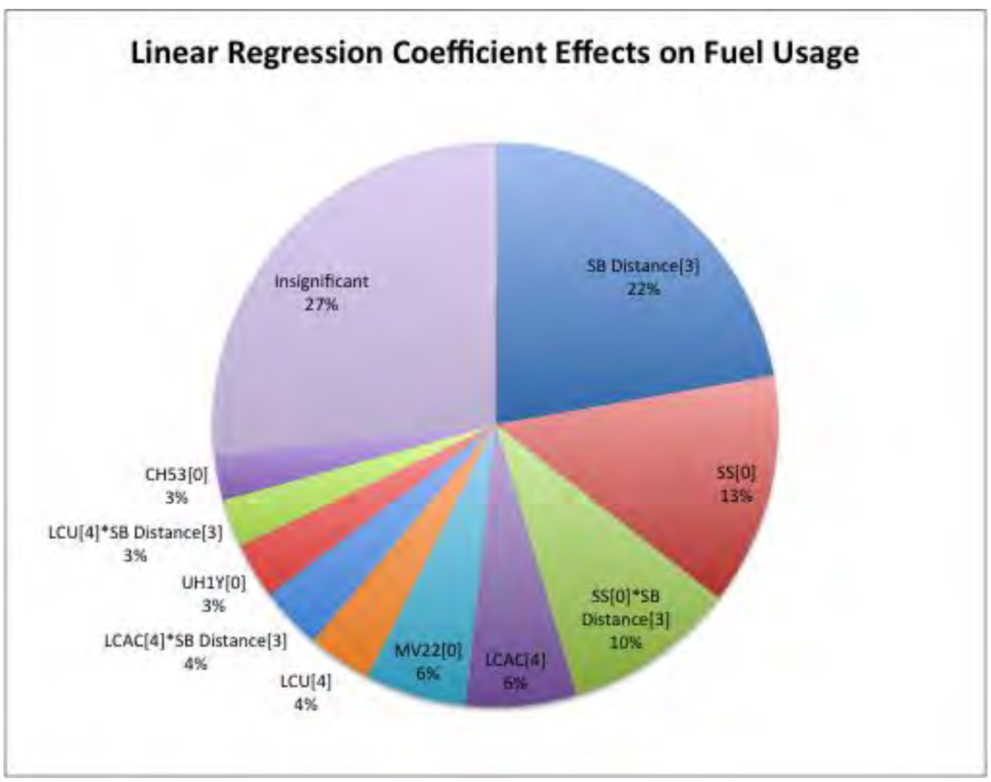


Figure 36. The coefficient proportional effects on fuel usage.

When interpreting Figure 35 and Figure 36, it is important to note that this presents proportional impact that each input variable has on its respective output response. As evident in Figure 35 and Figure 36, the factors with the greatest effect on both Assault Time and Fuel Usage are Seabase Distance and Sea State.

1. Representative Amphibious Readiness Group (ARG) Experimentation

As a follow up excursion to the wide range of variables initially explored, it was decided to test a connector configuration representative of a typical ARG. This configuration represents a capability baseline in which to evaluate performance of the system. The range of ARG configurations tested is listed in Table 8 as described in detail in Appendix A.

Table 8. Representative Amphibious Readiness Group (ARG).

ARG Ship	Well-deck Spots	#LCU	#LCAC	Helo Spots	# MV-22	# CH-53	# UH1-Y
LHD	4	a) 0	a) 3	9	10	4	3
		b) 2	b) 0				
LPD	4	a) 1	a) 0	2	2	0	0
		b) 0	b) 2				
LSD-41	4	a) 3	a) 0	2	0	0	0
		b) 0	b) 4				
LSD-41	4	a) 3	a) 0	2	0	0	0
		b) 0	b) 4				

For this second iteration of simulation, a Nearly Orthogonal Latin Hypercube (NOLH) design was selected for this experiment. The NOLH design allows a wide range of factor space to be explored, with a minimal impact of correlation error. A visual representation of the employed NOLH design is shown in Figure 37.

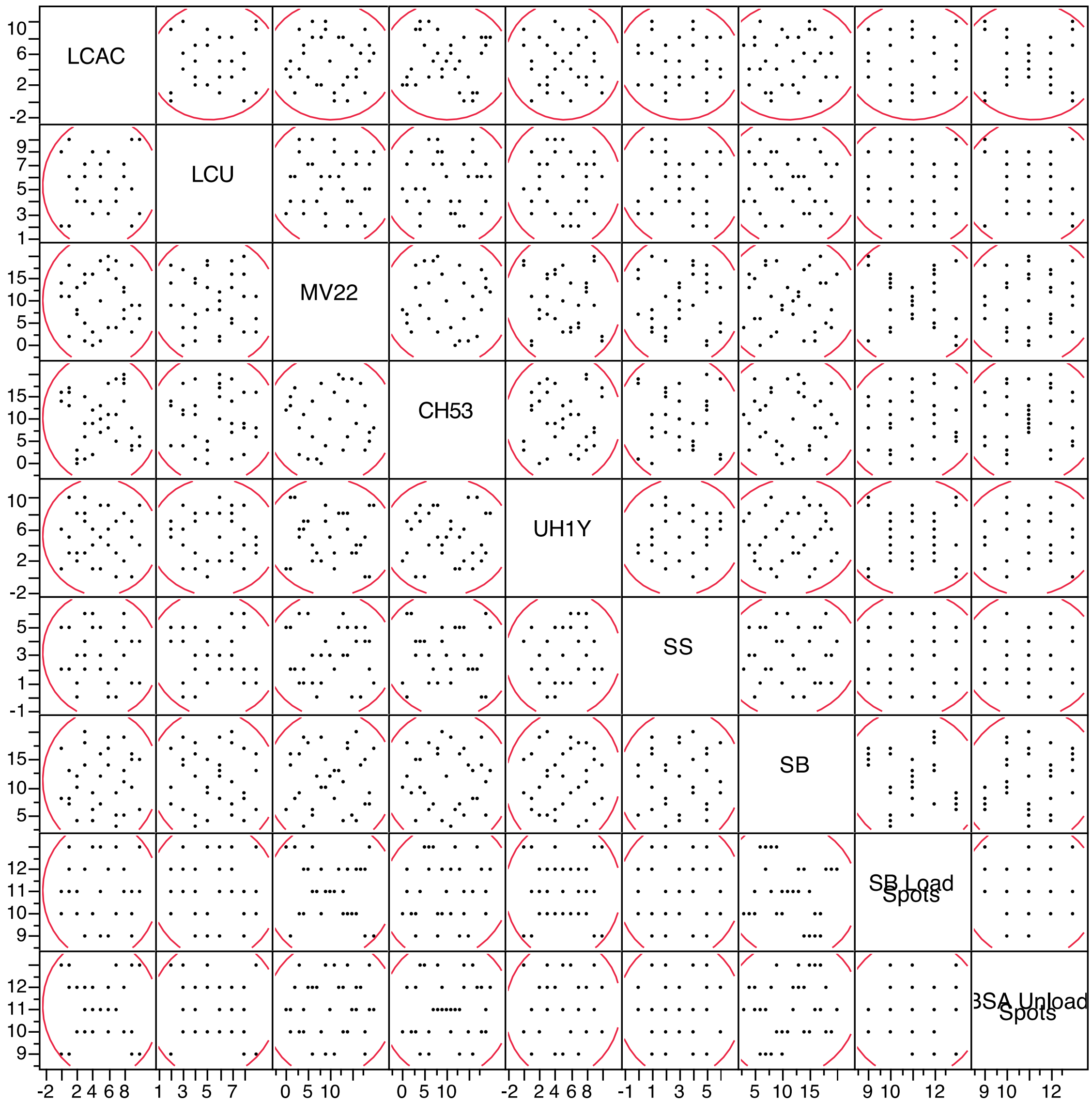


Figure 37. Nearly Orthogonal Latin Hypercube Experiment Design.

This experimental design was executed through the ExtendSim discrete event simulation model. The analysis and results of the output responses of the model are shown in Figure 38 and Figure 39.

Summary of Fit	
RSquare	0.851335
RSquare Adj	0.793162
Root Mean Square Error	2.539593
Mean of Response	14.10488
Observations (or Sum Wgts)	33

Term	Orthog Estimate
SB	3.381510
SS	2.789928
LCAC	-1.904614
CH53	-1.252806
LCU	-1.062384
MV22	-0.425874
UH1Y	0.111561
SB Load Spots	-0.058404
BSA Unload Spots	0.016422

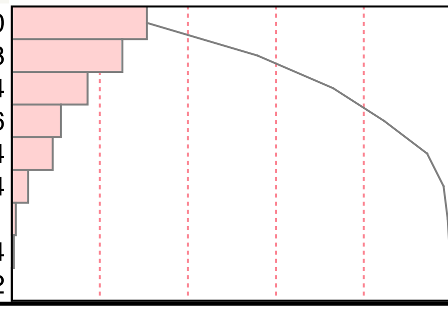


Figure 38. Analysis results of assault time.

Summary of Fit	
RSquare	0.884018
RSquare Adj	0.838634
Root Mean Square Error	268692.2
Mean of Response	1617189
Observations (or Sum Wgts)	33

Term	Orthog Estimate
SB	445254.7
SS	339629.2
LCAC	206191.3
UH1Y	121564.0
MV22	102698.9
LCU	44990.4
SB Load Spots	7210.0
CH53	-3224.3
BSA Unload Spots	-58.7

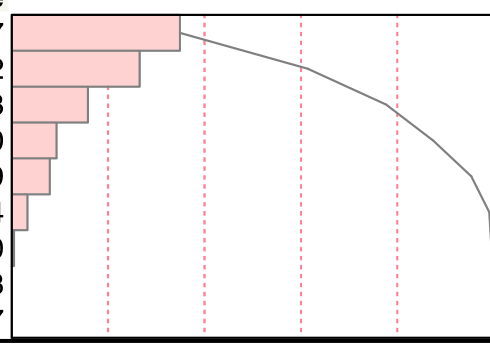


Figure 39. Analysis results of fuel used.

As evident by the above analysis results, the R^2 values indicate a good fit of the predicted model coefficients to the measured data. The Pareto charts provided also show coefficient results that are consistent with the findings from the previous full factorial simulations. These results provide confidence in the findings that there are no significant quadratic effects of the model, and that the model can be represented in a linear regression model.

2. Significant Effects of Connector Performance

An additional research goal set forth by this study was to determine the effects of system performance and fuel economy as a result of examining specific connector platform contributions to the seabase. In order to accomplish this objective, a third iteration of the simulation was performed, again using a NOLH design, but with a variation of fixing the Seabase Distance and Sea State variables to a constant level. This approach allowed these effects to be isolated or removed from the problem, allowing the connector platforms to be more easily evaluated. When examining the distribution of results completed from this iteration, it was observed that nearly half of all favorable performing simulation runs occurred when the Seabase distance was less than 11 nautical miles (nmi), as shown in Figure 40. In the simulations that were run in which the Seabase Distance factor was greater than 11 nmi, the predominating factor influencing overall system fuel consumption was Sea State.

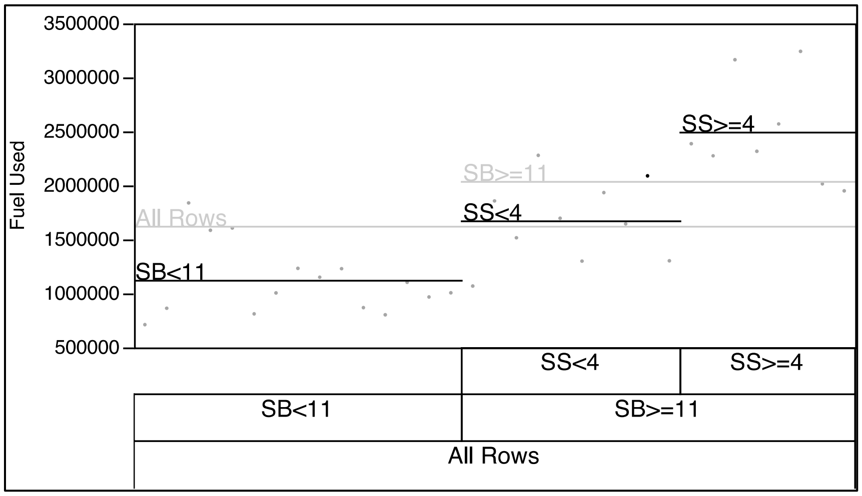
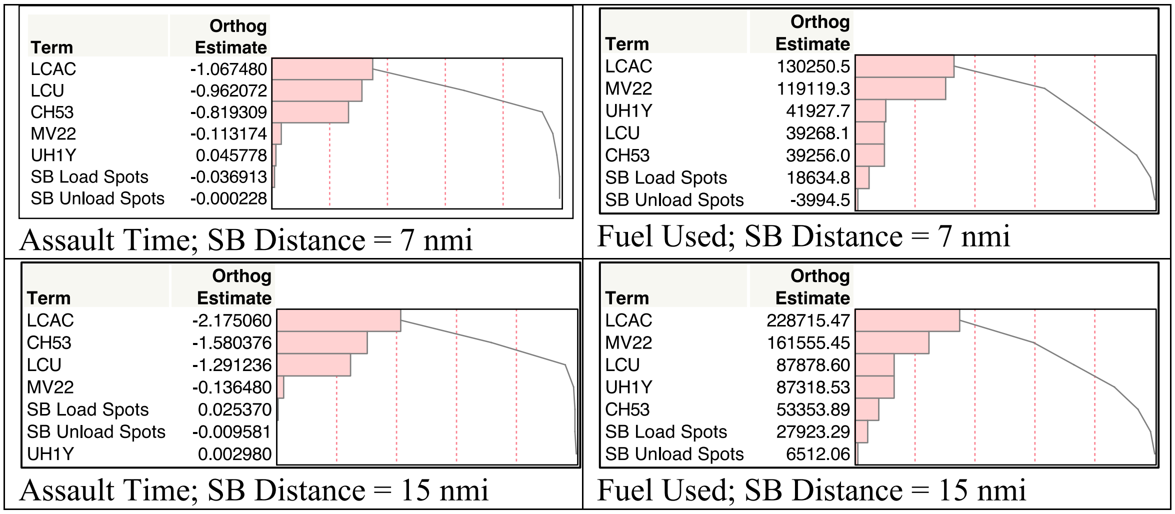


Figure 40. The effects of holding the seabase distance and sea state constant show that the variation in the model is predominantly caused by sea state when it is a variable.

After analyzing this information, an excursion was made to run a 3rd DOE iteration with two variations:

- Fix the Sea State to SS4.
- Set the Sea Base distance at 7 nmi and 15 nmi throughout the simulation runs.

The ExtendSim model was repeated for the reduced set of 7 variables, consistent with the previous NOLH experimental design. A first iteration was conducted with the SB Distance set at 7 nmi, and a second iteration was performed with the SB Distance set at 15 nmi. The results of these simulation runs are shown in Figure 41.



Assault Time; SB Distance = 7 nmi

Term	Orthog Estimate
LCAC	-1.067480
LCU	-0.962072
CH53	-0.819309
MV22	-0.113174
UH1Y	0.045778
SB Load Spots	-0.036913
SB Unload Spots	-0.000228

Fuel Used; SB Distance = 7 nmi

Term	Orthog Estimate
LCAC	130250.5
MV22	119119.3
UH1Y	41927.7
LCU	39268.1
CH53	39256.0
SB Load Spots	18634.8
SB Unload Spots	-3994.5

Assault Time; SB Distance = 15 nmi

Term	Orthog Estimate
LCAC	-2.175060
CH53	-1.580376
LCU	-1.291236
MV22	-0.136480
SB Load Spots	0.025370
SB Unload Spots	-0.009581
UH1Y	0.002980

Fuel Used; SB Distance = 15 nmi

Term	Orthog Estimate
LCAC	228715.47
MV22	161555.45
LCU	87878.60
UH1Y	87318.53
CH53	53353.89
SB Load Spots	27923.29
SB Unload Spots	6512.06

Figure 41. Comparative results between 7 and 15 nmi SB distances are shown.

Through the analysis results shown in Figure 41, several commonalities can be observed in the data between the 7 and 15 nmi SB Distance cases:

- In both cases, the MV-22 is a high fuel consumer, but a low contributor to the Assault Time metric. This could be due to the fact that the MV-22 Osprey is a very capable platform in terms of effective range, but in the short range problem presented in the Amphibious Assault scenario, the platform may be inappropriately utilized.
- The LCAC is also a high fuel consumer, but is also a high performer to the Assault Time metric. In this case, the use of the LCAC is directly proportional between achieving the successful assault, as well as expending fuel. The operational decision maker would need to balance the priorities between the rate of amphibious landings performed and the resultant fuel economy.
- In the scenario where the Seabase is offset less than 11 nmi (7 nmi case), the LCU provides a greater contribution than the CH-53 platform. However, in the scenario where the Seabase is offset greater than 11 nmi (15 nmi case), the CH-53 provides more timely performance than the LCU, with minimal impact of fuel use. This may be attributable to the comparable speed advantage of the CH-53 over the LCU.

V. CONCLUSIONS

A. DOE ANALYSIS AND FINDINGS

Following completion of the simulation trials, it was determined that sufficient information was available to develop inferences on system performance and provide recommendations to the project stakeholder.

As consistent with current doctrine and best practices, the model validates the planning considerations with respect to SSD and Sea State. The model provides statistical evidence to support the conclusion that these two factors provide the greatest amount of impact against achieving energy efficiencies while conducting the assault. Given the MOE's of Assault Time and Fuel Usage derived from the top level stakeholder objectives, the following findings and recommendations were developed with respect to the MOE's.

1. Operational Effects of Seabase Standoff Distance (SSD)

Significant interactions exist when operating LCACs and LCUs in different SSD conditions. As shown in the interaction plots in Figure 42, the quantity of LCAC's and LCUs are not significant when operating at a close distance from shore. As the standoff distance is increased, the quantity of landing craft connectors used to transport the MEB become more significant. Thus, the recommendation is provided to increase the number of LCACs & LCUs utilized proportionally as the SSD is increased.

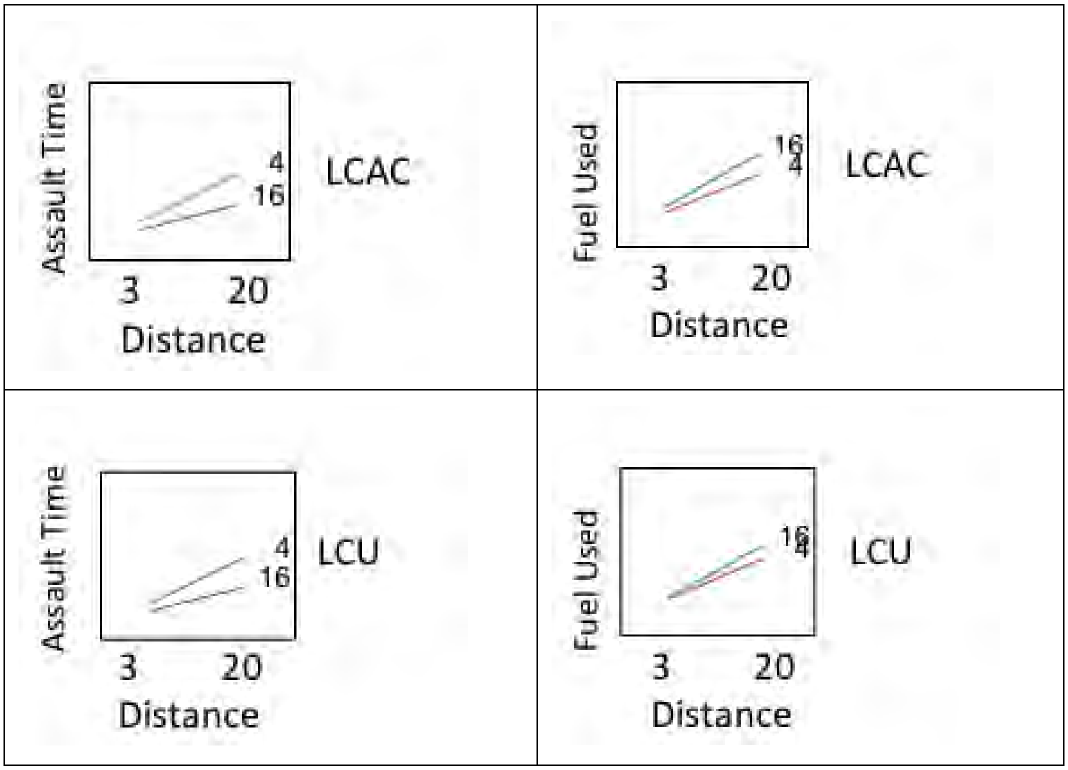


Figure 42. Interaction plots of assault time and fuel usage vs. seabase distance.

2. Operational Effects of Sea State

Significant interactions exist when positioning the Seabase in different standoff distances and sea state combinations. As shown in the following interaction plot Figure 43, the operational impacts of high sea states are not detrimental when operating at a low stand-off range. When the Seabase standoff range is increased, the sea state environment has a pronounced negative effect on the performance of the assault.

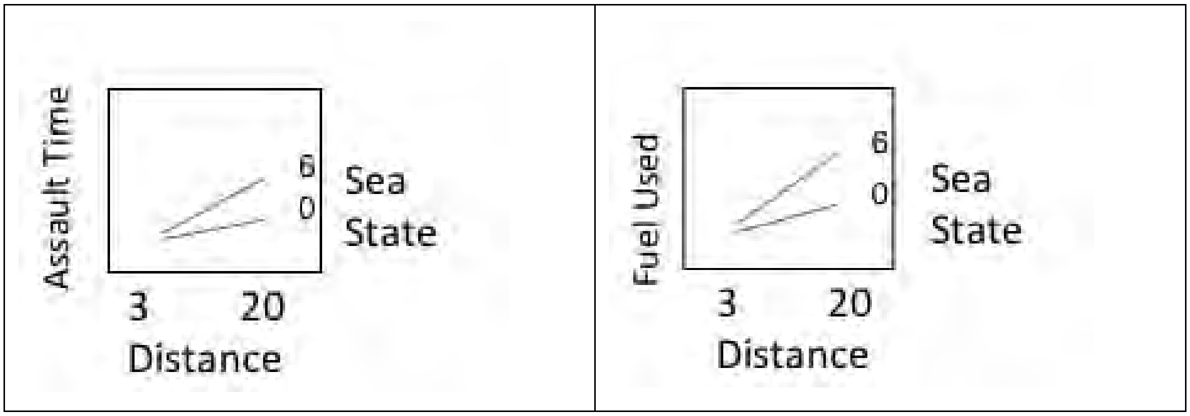


Figure 43. Interaction plots of assault time and fuel usage vs. sea state.

When operating in high sea states cannot be avoided and accommodations in Sea Base standoff distance is not possible, then there are still efficiencies possible to be gained in this scenario. The interaction plot in Figure 44 shows the Assault Time and Fuel Usage effects of varying numbers of LCAC and LCU with respect to Sea State.

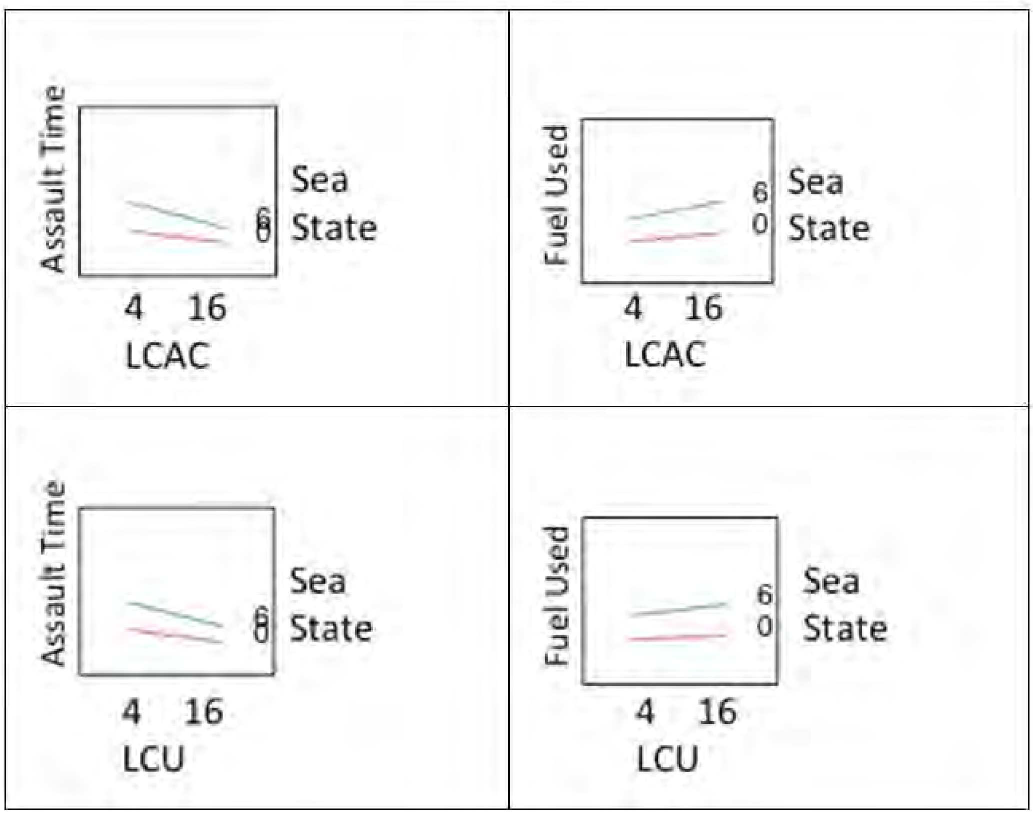


Figure 44. Interaction plots of assault time and fuel usage vs. sea state.

As can be interpreted by Figure 44, the negative effects of the Assault Time by high Sea State can be mitigated, by increasing the quantity of LCUs or LCAC connectors. When considering the interests of fuel efficiencies, increasing the quantities of LCUs during high sea state provides less of an impact on fuel consumption than that of the LCACs. Thus, the recommendation is provided as follows:

- When conducting the amphibious assault in high sea state conditions, it is recommended to decrease the SSD as operationally practicable.
- When the above recommendation is not feasible, it is recommended to utilize LCUs to conduct the landing craft operations over LCACs to optimize energy efficiencies in this operational scenario.

3. Operational Effects of Connector System Configuration

As described in IV.C.1IV.C.2, the composition of the connector configurations was discovered to have an operational impact on overall fuel economy over the 30-day mission. The attributes of the MV-22B Osprey used in this simulation certainly indicate an overall capable platform over a wide breadth of mission areas. However, in the limited scope of the Amphibious Assault Mission in which lift capacity over a relatively short distance is preferred, the MV-22 seems to be inappropriately utilized for this application. The recommendation is provided to avoid or minimize use of the MV-22 connector during the Amphibious Assault mission when fuel savings is considered a priority. Alternatively, the MV-22 platform would be considered most effectively utilized when conducting longer range missions, when the fuel usage rate would be improved over a longer time average.

The LCAC has proven to be a significant effective component in supporting the Amphibious Assault mission, albeit as a cost of being the system’s highest fuel consumer. The recommendation is provided to judiciously employ the LCAC during the mission, and consider managing the use of this connector during different phases of the assault mission.

B. RESPONSE TO RESEARCH QUESTIONS

With the intent of concluding this study to answer the research questions derived from the sponsor needs statement, the following responses are provided with respect to the research questions.

1. Research Question #1 "Can Improved Fuel Efficiency be Reached through Changes in DOTMLPF while Maintaining Mission Capability?"

There are several different ways in which fuel efficiency can be obtained through Doctrine changes in this mission area. However, the extent of fuel savings achieved may vary on factors within the MAGTF's control as well as some variables outside of direct control. It was documented that fuel savings are directly proportional to the Seabase distance and sea state effects during operations, which may not always be able to be influenced by the landing force. However, it was determined that when these adverse conditions exist, the LCU may be able to provide better fuel economy over employment of the LCAC.

2. Research Question #2 "What Particular Connectors have the Most Effect on Fuel Efficiency?"

This question was satisfactorily addressed by this study, as addressed by Figure 41. the LCAC and MV-22 connectors have the most significant negative effects on overall fuel efficiency during the mission. However, it was determined that the LCAC also has the most positive effect on performance of the Amphibious Assault mission, thus its employment should be considered judiciously when favoring payload throughput vs. fuel efficiencies. It was determined that the use of MV-22 should be further reviewed for its operationally effective contributions to system performance.

3. Research Question #3 "Can the Environment Affect the Ability of the MEB to Achieve Better Fuel Efficiency?"

This question was satisfactorily answered by this study. As explained in Section V.A.2, environmental effects such as Sea State have a pronounced negative effect on fuel

efficiency. However, this effect can be mitigated to an extent through operational workarounds, such as decreasing the SSD, and employing LCUs in place of LCACs.

C. RELATIONSHIP OF MODEL RESULTS TO CURRENT USMC DOCTRINE

As the USMC prepares to conduct the next A2/AD operations, the findings of this research support the current assumptions stated in USMC doctrine with respect to planning factors for seabasing operations. The distance from the seabase to the shore and sea state, which are among the many planning factors of an amphibious assault, have been shown to be correlated to the consumption of energy to the MEB during amphibious operations. This research indicates that these factors should be considered early and frequently re-evaluated for their impact on the amphibious operations. USMC doctrine highlights the transit distance and sea state as factors to consider when discussing the strategy of seabasing. MCWP 3–31.7 Seabasing, states:

> It must be stressed that off-loading of the MPSRON or AFOE conducted across the beach is much slower to accomplish than off-loading conducted in an SPOD and is impacted by transit distance, sea state, winds, lighterage and landing craft available, and many other factors. (Office of the Chief of Naval Operations 2006, 37)

Distance and sea state are listed among the factors to be considered when offloading the Assault Follow-On Echelon (AFOE) personnel and cargo, but this research indicates that these two variables play a crucial role in the reduction of energy consumption to the MEB. In scenarios where the assault forces are required to debark from distances farther out due to threats or need to maneuver, there should be strong consideration to relocate the ships closer when there is operational availability to do so. The model results indicate that the ability to reduce the distance from the seabase to the shore will translate into an increase in the energy resources, which may be made available to conduct additional missions.

In addition to the reduction in energy consumption relative to the seabase distance, the ability to sustain the forces ashore is also enhanced by shorter distances.

> The smooth flow of supplies and personnel to the seabase and into the JOA will be one of the determining factors in a successful seabasing

> operation. This flow has many variables, including the type and size of the operation being supported from the seabase, amount of air and sealift available, the distance from the advanced base/ALSS/FLS to the seabase and JOA, the infrastructure available (airfields, port facilities, material handling equipment, etc.) in or out of the JOA, C2 of air and sealift, coordination and prioritization of supply, equipment and personnel movement and most importantly, personnel required to execute this transportation and distribution function (Office of the Chief of Naval Operations 2006, 57).

During operations, personnel and supplies will need to flow from the seabase to the operational areas. Reducing this distance will help to ensure that the mission effectiveness of the MAGTF is maintained.

D. AREAS OF FURTHER RESEARCH

In an effort to continue efforts of the MEB energy footprint reduction, further studies are recommended to investigate additional energy efficiency opportunities across the DOTMLPF solution space. Within the boundaries of the functional architecture constructed from the Amphibious Assault mission thread description, several opportunities exist which could benefit from investigative efforts. The following research areas are recommended for follow-on studies:

1. Sea-Base Composition

Modeling and Simulation efforts are recommended to evaluate the efficiency and capability performance of different ARG and associated seabase support ship configurations. The effects of additional Military Sealift Command (MSC) support ships as well as varying quantities and types of ships should be explored. Additionally, capabilities of newly delivered and future planned ship class applications should be evaluated, such as the new *America* Class LHA(R) amphibious assault ship, the MSC Mobile Landing Platform USNS Montford Point (T-MLP-1) and other planned acquisitions.

2. Aircraft and Landing Craft Technologies

Modeling & Simulation efforts are recommended to evaluate the efficiency and capability performance of newly developed and future planned connector platforms to be added to fleet inventory. Examples of new advanced capability platforms to be examined include:

- Joint High Speed Vessel (JHSV) landing craft
- K-MAX Heavy lift Vertical Takeoff Unmanned Aerial Vehicle (VTUAV)
- Future technology development related to Air Supported Vessel (ASV) landing craft
- LCU replacement with Surface Connector Replacement (SC(X)(R)) landing craft

3. Sustainment Phase Decomposition and Modeling

During this study, the function "F3 – Sustain MEB" was largely abstracted in order to focus more resolution of the "F2 – Perform Assault" function. There are many operational activities and events that occur during this sustainment phase which warrant further investigation. Aspects such as reorganization of the "Iron Mountain," strategies for the staging and distribution of water and fuel, and other areas within the operational construct should be evaluated for fuel efficiency opportunities.

4. Loading and Landing Order of Connectors

An additional DOTMLPF aspect for future research efforts that should be considered is the scheduling of assets at the Seabase and Beach Support Area during loading & unloading operations. This is another area that was simplified during the modeling process, but could benefit from further investigation and simulation. The sequencing and prioritizing of certain MEB assets while being loaded on the Seabase, as well as unloaded in the BSA, may have the potential to affect the fuel efficiency of the overall system's performance.

E. SUMMARY AND FINAL OBSERVATIONS

In response to the USMC E2O stakeholder needs statement, the Capstone team applied a structured Systems Engineering approach to evaluate possible opportunities of

energy efficiency across the DOTMLPF solution spectrum within the operational domain of an Amphibious Assault. A comprehensive bottoms-up functional architecture was derived from the current MEB physical architecture as a basis for the development of a discrete event simulation model. A DOE approach was developed to be responsive to the existing variables available within the system architecture. Based on the model results, analysis and conclusions were obtained to make recommendations to the stakeholder on best operational conditions in which to achieve fuel economy with response to environmental factors.

The effort completed by the Capstone team provides a thorough examination in one aspect of the A2/AD scenario, with a foundation established to enable future studies to continue research in this area. This includes further DOTMLPF investigations in the Seabase configuration, future connector platform technologies, and further granulation of modeling and simulation capabilities in the MEB Beach Support Area.

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APPENDIX A

ARG COMPONENT SHIPS

Figure 45. The amphibious command ship USS Mount Whitney (LCC 20, LCC 19 class). Photograph by Mass Communication Specialist 3rd Class Heidi McCormick, U.S. Navy. Retrieved from *Wikipedia*.

Ship Information (Marine Corps Combat Development Command, 2001, 2)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LCC 19	Command	209	3015	1
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
0	0	0	0	0
Ship Specialties / Additional Capabilities				
Landing force command and control facilities				

Figure 46. The amphibious assault ship USS Bon Homme Richard (LHD 6, LHD 1 class). Photograph by Photographer's Mate 2nd Class Jennifer Swader, U.S. Navy. Retrieved from *Wikipedia*.

Ship Information (Marine Corps Combat Development Command, 2001, 4)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LHA 1	Assault (GP)	1903	28700	9
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
107	76	26	1	4
Ship Specialties / Additional Capabilities				
Command and control and Medical				

Ship Information (Marine Corps Combat Development Command, 2001, 7)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LHD 1	Assault (MP)	2098	24012	9
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
322	50	28	3	2
Ship Specialties / Additional Capabilities				
Command and control and Medical				

Figure 47. The amphibious transport dock ship USS Mesa Verde LPD 19 (LPD 17 class) Photograph by Mass Communication Specialist 2nd Class Jason R. Zalasky, U.S. Navy. Retrieved from *Wikipedia*.

Ship Information (Marine Corps Combat Development Command, 2001, 10)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LPD 4	Transport Dock	885	14000	2
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
168	50	20	1	1
Ship Specialties / Additional Capabilities				
Command and control and Medical				

Ship Information (Marine Corps Combat Development Command, 2001, 13)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LPD 17	Transport Dock	799	25000	2
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
188	50	31	2	1
Ship Specialties / Additional Capabilities				
Command and control and Medical				

Figure 48. The amphibious dock landing ship USS Harpers Ferry (LSD 49). Photograph by Chief Mass Communication Specialist Ty Swartz, U.S. Navy. Retrieved from *Wikipedia*.

Ship Information (Marine Corps Combat Development Command, 2001, 19)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LSD 41	Dock Landing	504	11831	2
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
440	50	27	4	3
Ship Specialties / Additional Capabilities				
Large number of LCACs carried				

Ship Information (Marine Corps Combat Development Command, 2001, 22)		**Landing Force/Lift Specifications**		
Ship Class	**Primary Mission**	**Troops (surge)**	**Vehicle Space(ft^2)**	**Helicopter Spots**
LSD 49	Dock Landing	508	20200	2
Well Deck Capacity				
Length	**Width**	**Height**	**LCAC**	**LCU**
180	50	30	2	1
Ship Specialties / Additional Capabilities				
Limited				

APPENDIX B

TROOPS, EQUIPMENT, AND CARGO ESTIMATES

Nomenclature	Crew	CE	GCE	ACE	CSS	TOTAL	Fuel Rate (G/HR)	WT (LBS)	AREA (FT^2)	Required Transport
Bridge Erection Boat	4	0	0	0	1	**1**	**2**	10000	23	LVSR MKR18 Cargo
Medium Girder Bridge	0	0	0	0	1	**1**	**2**	63700	64	LVSR MKR18 Cargo
Ribbon Bridge Raft	0	0	0	0	2	**2**	**2**	31000	240	LVSR MKR18 CargoA1
SEE Tractor	1	0	4	1	2	**7**	**2**	10000	160	LVSR MKR16 Tractor/M 870
LT WT Decon Apparatus	0	0	20	10	10	**40**	**10**	4400	100	M1097A2 HMMWV
MK 2 MOD 0 MINE CLEARANCE SYSTEM TRAILER/M3 53 trailer	4	0	9	0	2	**11**	**4.5**	3560	46	M813A1 5 ton truck
AVLB Bridge	4	0	4	0	0	**4**	**2**		160	
JAB Chassis/Bridge (M-1A1)	0	0	2	0	0	**2**	**1.7**	140000	160	LVSR MKR18 Cargo
MK-18A1 Ribbon Bridge Trailer	0	0	0	0	10	**10**	**2**	21800	159	LVSR MKR18 Cargo
2 1/2 Cubic Yard Bucket	0	0	2	2	4	**8**	**2**	3400	39	MK23 7 ton
Compact Ditcher	1	0	0		1	**1**	**2**			
M9 Armored Combat Excavator	1	0	6	0	0	**6**	**2**	54000	215	30 mph
T-5 Dozer	1	0	0	2	4	**6**	**2**			
D-7 Dozer	1	0	6	6	8	**20**	**2**	50000	273	LVSR MKR16 Tractor/M 870
Dozer with Multi-bucket	1	0	0	2	2	**4**	**2**	27700	110	LVSR MKR16 Tractor/M 870

Road Grader	1	0	0	2	2	**4**	**2**	37700	256	LVSR MKR16 Tractor/M 870
420C Roller	1	0	0	1	2	**3**	**2**	23700	167	LVSR MKR16 Tractor/M 870
HIGH SPEED, HIGH MOBILITY, (HSHM) CRANE	2	0	0	2	2	**4**	**2**	69800	354	LVSR MKR16 Tractor/M 870
Nomenclature	**Crew**	**CE**	**GCE**	**ACE**	**CSS**	**TOTAL**	**Fuel Rate (G/HR)**	**WT (LBS)**	**AREA (FT^2)**	**Required Transport**
ROUGH TERRAIN AIR MOBILE CRANE (AMC)	1	0	1	4	6	**11**		24230	205	AIR TRANS
50K lb Rough Handling Container	1	0	0	1	5	**6**		103700	402	9.5 gph
Extendable Boom Forklift Truck (EBFL)	1	0	2	12	12	**26**	**2**	29300	207	LVSR MKR16 Tractor/M 870
4K lb Forklift	1	0	3	5	7	**15**	**2**	13400	127	LVSR MKR16 Tractor/M 870
10K lb Forklift	1	1	7	7	12	**27**	**2**	36600	247	LVSR MKR16 Tractor/M 870
AM-2 Mat 2X12 FT Panels 432 SQFT	0	0	0	0	2268	**2268**		2700	59	463L Pallet
AM-2 Mat 2X6 FT Panels 216 SQFT	0	0	0	0	2	**2**		1350	59	463L Pallet
DECON Apparatus	0	0	0	4	0	**4**		4000	59	463L Pallet
MOMat	0	0	0	12	66	**78**	**4.5**	4000	59	463L Pallet
10 KW Generator	0	4	18	18	20	**60**	**4.5**	1242	14	M116 trailer and the LTT-MCC trailer
30 KW Generator	0	2	9	25	12	**48**	**4.5**	2931	19	USMC M353 trailer

60 KW Generator	0	1	10	4	4	**19**	**2**	4042	21	USMC M353 trailer
100 KW Generator	0	0	2	9	4	**15**	**2**	7500	29	MK23 7 ton
AIR COMPRESSOR WITH PNEUMATIC TOOLS	0	0	1	2	4	**7**		7300	134	MK23 7 ton
AMPHIB ASSLT Fuel System 600K GAL (AAFS)	6	0	0	0	2	**2**		140164	2843	
SHOP EQUIPMENT, GENERAL PURPOSE, SET NO. 1	0	0	1	1	3	**5**		31000	84	
Helo Refuel System (HERS)	6	0	0	4	0	**4**		6134	1250	Air Lift
Fuel SIX-CON (1EA)	0	6	25	20	35	**86**	**2**	2300	52	MK23 7 ton/LVSR MKR18
SIX-CON Fuel Pump	0	2	6	5	10	**23**		2300	52	
Nomenclature	**Crew**	**CE**	**GCE**	**ACE**	**CSS**	**TOTAL**	**Fuel Rate (G/HR)**	**WT (LBS)**	**AREA (FT^2)**	**Required Transport**
500 GAL Fabric Fuel Drum	0	0	0	0	25	**25**		3235	23	Air Lift
Water SIX-CON	0	6	2	6	80	**94**	**2**	10000	52	MK23 7 ton/LVSR MKR18
SIX-CON Water Pump	0	2	1	3	25	**31**		2300	52	
500 GAL Fabric Water Drum	0	0	10	30	24	**64**		4565	26	Air Lift
TWDS	0	0	3	2	6	**11**		7150	141	
TWDS Pump	0	0	1	1	3	**5**		6250	110	MK23 7 ton
TWDS Distribution Point	0	0	1	1	1	**3**		1500	28	
50K GAL Water Tank	0	0	0	0	10	**10**		1640	31	
20K Gal Water Tank	0	0	0	0	5	**5**		1000	15	
40 Ton Low Boy Trailer	0	0	4	7	13	**24**	**2**	20000	340	LVSR MKR16 Tractor/M870

7 Ton Dump Truck (AMK29)	2	0	5	5	15	**25**	**4.5**	37200	210	LVSR MKR16 Tractor/M 870
Bridge Erection Set	6	0	0	0	1	**1**	**2**	5960	96	MK23 7 ton
613C WATER DISTRIBUTOR	0			1	1	**2**		33500	300	
AAVP-7	3	4	48			**52**	**1.2**	54000	214	
LAV-25	6	4	25			**29**	**5.7**	28000	214	
LAV-MEWESS	6	1	2			**3**	**5.7**	28000	214	
M1A1 MBT	4		14			**14**	**1.7**	120000	160	
M88A2 Tank Retriever	4		2			**2**	**1.7**	135000	160	
M1123 (HMMWV) (cargo/troops)	4	8	41	10	20	**79**	**10**	5850	121	
M1167 HMMWV (weapons)	4	4	23	4	6	**37**	**10**	11250	121	
M1114 HMMWV, ARMAMENT CARRIER	4	4	15	6	10	**35**	**10**	12140	121	
M997A2 Ambulance	3	2	6	2	10	**20**	**10**	7700	121	
M1165A1 COMMAND AND CONTROL	6	8	2	1	1	**12**	**10**	9870	121	
7 TON, MK23 MTVR TRUCK, CARGO	3	2	6	4	10	**22**	**4.5**	27700	214	
7 TON, MK27 MTVR TRUCK, CARGO XL	3				10	**10**	**4.5**	30000	263	
Nomenclature	**Crew**	**CE**	**GCE**	**ACE**	**CSS**	**TOTAL**	**Fuel Rate (G/HR)**	**WT (LBS)**	**AREA (FT^2)**	**Required Transport**
7 TON, TRUCK, TRACTOR, MK31 MTVR	3		2	2	20	**24**	**4.5**	27200	201	
7 TON TRUCK, WRECKER, , MK36	3		2		5	**7**	**4.5**	49100	263	
7 TON HIMARS Resupply	3		4		4	**8**	**4.5**	62200	245	

MK37/										
MK48 POWER UNIT, FRONT, 12 1/2 TON,	0	0	0	0	0	**0**	**2**	25300	159	
MK14 TRAILER, 22 1/2 TON, CONTAINER HAULER,	0	0	6	6	14	**26**	**2**	16000	159	LVSR MKR18 Cargo
MK15 TRAILER WRECKER/R ECOVERY,	0	0	2	2	6	**10**	**2**	28000	152	
MK16 SEMI-TRAILER ADPATER, 5th Wheel	0	0	6	6	10	**22**		16200	130	LVSR MKR18 Cargo
TACTICAL WATER PURIFICATIO N SYSTEM	6	0	0	0	3	**3**		9500	98	MK23 7 ton
TRUCK, CARGO, 10X10 LVSR MKR18	3	4	6	4	40	**54**	**2**	59900	294	
TRAILER, PALLETIZED LOADING SYS, M1076	0		2	2	10	**14**	**2**	16500	216	LVSR MKR16 Tractor
FLATRACK, PALLETIZED LOADING SYS, M1077/MK1 077	0	4	4	4	20	**32**		2900	164	LVSR MKR16 Tractor
M1164 TRAILER (30 rds) M352 120MM Mortar	0		10		2	**12**	**4.5**	2725	29	M1123 (HMMWV)
TRAILER, CARGO, 3/4 TON, M101A3 (HMMWV)	0	16	60	16	20	**112**	**10**	1340	75	M1123 (HMMWV)
M149 TRAILER, TANK, WATER, 400 GALLON,	0	0	0	0	0	**0**	**4.5**	5775	89	MK23 7 ton
MK38 TRAILER, CARGO, RE-	0		10		4	**14**	**4.5**	22000	214	MK23 7 ton

SUPPLY F/(HIMARS),										
MK970 SEMI-TRAILER, AIRCRAFT REFUELER, 5000 GALLON,	0			4	10	**14**	**2**	53700	239	LVSR MKR16 Tractor
Nomenclature	**Crew**	**CE**	**GCE**	**ACE**	**CSS**	**TOTAL**	**Fuel Rate (G/HR)**	**WT (LBS)**	**AREA (FT^2)**	**Required Transport**
M870A2-S SEMI-TRAILER, LOWBED, 40 TON,	0		4	2	10	**16**	**2**	19600	339	LVSR MKR16 Tractor
M870A2E1 SEMI-TRAILER, LOWBED, 50 TON,	0				6	**6**	**2**	23600	423	LVSR MKR16 Tractor
MK149 TRAILER, TANK, WATER, 600 GALLON,	0	8	16	8	16	**48**	**4.5**	15880	135	MK23 7 ton
HYPOCHLORINATION UNIT, PURIFICATION	0	0	1	1	2	**4**		450	4	HMWVV

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